U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-285 531

Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III. Asbestos

Syracuse Research Corp, N.Y.

Prepared for

Environmental Protection Agency, Washington, D.C.

Aug 78

EPA 560/6-78-005

PB 285 531

CHEMICAL MARKET INPUT/OUTPUT ANALYSIS OF SELECTED CHEMICAL SUBSTANCES TO ASSESS SOURCES OF ENVIRONMENTAL CONTAMINATION: TASK III. ASBESTOS

August 1978

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SPRINGFIELD, VA. 22161

Office of Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 560/6-78-005	2.	3. RECIPIENT'S ACCESSION NO. PB285531

4. TITLE AND SUBTITLE Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination-Task III. Asbestos	5. REPORT DATE August 1978 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) William M. Meylan, Philip H. Howard, Sheldon S. Lande , Arnold Hanchett	8. PERFORMING ORGANIZATION REPORT NO TR 77-515
9. PERFORMING ORGANIZATION NAME AND ADDRESS Center for Chemical Hazard Assessment Syracuse Research Corp. Merrill Lane Syracuse, N.Y. 13210	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. EPA 68-01-3224, Task III
12. SPONSORING AGENCY NAME AND ADDRESS Office of Toxic Substances U.S. Environmental Protection Agency Washington, D.C. 20460	13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report considers the sources of asbestos environmental contamination. Marketing information, available monitoring data, and engineering assumptions were used to estimate asbestos emissions. Chrysotile is the more common commercial mineral form of asbestos, although others such as crocidolite, amosite, and anthophyllite are also commercially important. Asbestos is used in thousands of products including friction materials (brakes and clutches), asbestos-cement pipe and sheet, roofing, paper, flooring, insulation, packing and gaskets, textiles, coating and paints, and plastics. The available information would not allow for any quantitative estimates and rarely was an ambient level attributable to a particular source. Exceptions were crushed serpentinite rock containing asbestos that was used to pave roads and driveways, demolition of buildings containing asbestos construction material, and automotive brake linings adjacent to toll plazas where cars brake to a stop. Municipal incineration may also be a potential source of significant asbestos fiber emission to ambient air. Release of asbestos fibers from A/C pipe used for drinking water appears to be minor, except where the water is very aggressive.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
asbestos chrysotile crocidolite brakes A/C cement roofing		

18. DISTRIBUTION STATEMENT Document is available to the public through the National Technical Information Service, Springfield, Va. 22151	19. SECURITY CLASS *(This Report)* 20. SECURITY CLASS *(This page)*	21. NO. OF PAGES 331 22. PRICE PC A15 MF A01

EPA Form 2220-1 (9-73)

EPA 560/6-78-005

TR 77-515

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TASK III. ASBESTOS

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Contract No. 68-01-3224 - Task III
SRC No. L1273-08

August 1978

Project Officer - Joseph J. Breen

Prepared for:

Office of Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

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1.0 INTRODUCTION

This study on the commercial market and environmental sources of asbestos was undertaken for the following reasons: (a) to consolidate the large volume of published literature in an attempt to describe the asbestos industry and the uses of asbestos in terms of marketing data and statistics, (b) to examine the potential for asbestos emissions from product manufacturing and product use, and (c) to quantitatively estimate asbestos emissions to the environment where possible. To date, no comprehensive attempt has been made to examine the sources and quantities of asbestos which may be released to the environment from asbestos-containing products as they relate to both their manufacture and use. Emission estimates are projected from available monitoring data and engineering assumptions.

2.0 DESCRIPTION OF ASBESTOS

2.1 Composition and Properties of Asbestos

"Asbestos" is not the name of a distinct mineral species but is a commercial term applied to fibrous varieties of several minerals differing widely in chemical composition, the fibers being diverse in length, strength, flexibility, and consequent usefulness (The Asbestos Factbook, 1970). Gary *et al*. (1972) define asbestos as:

> "(1) A commercial term applied to a group of highly fibrous silicate minerals that readily separate into long, thin, strong fibers of sufficient flexibility to be woven, are heat resistant and chemically inert, and possess a high electric insulation, and therefore are suitable for uses (as in yarn, cloth, paper, paint, brake linings, tiles, insulation, cement, fillers, and filters) where incombustible, nonconducting, or chemically resistant material is required; (2) A mineral of the asbestos group, principally chrysotile (best adapted for spinning) and certain fibrous varieties of amphibole (esp. tremolite, actinolite, and crocidolite); (3) A term strictly applied to the fibrous variety of actinolite."

The American Society for Testing and Materials (ASTM) has provided the following definition:

> "Asbestos is a generic term for a number of naturally occurring hydrated silicate fibers that, when crushed or processed, separate into flexible fibers made up of fibrils. Such materials are asbestiform. Minerals included in this definition of asbestos are the asbestiform varieties of serpentine (chrysotile), riebeckite (crocidolite), cummingtonite (amosite), anthophyllite, tremolite, and actinolite."

Another definition of asbestos was established by the Occupational Safety and Health Administration (OSHA) and appeared in the Federal Register (10/9/75, p. 47652, 47660). In this regulatory statement, the naturally occurring minerals chrysotile, amosite, tremolite, crocidolite, actinolite, and anthophyllite are specifically mentioned. These minerals are classified as "asbestos" if the individual crystallites have the following size characteristics: length - greater than 5 µm; maximum diameter - less than 5 µm; and a length-to-width diameter ratio of three or greater. Material containing any of the above minerals with the listed size characteristics will be defined as "asbestos." Sometimes the literature refers to the common asbestoses with jargon names: "white asbestos" for chrysotile and "blue asbestos" for crocidolite (Berger and Oesper, 1963).

While the asbestoses differ in chemical composition, they share similar polymeric silicate structure. The fibrile-like structures of the asbestoses result from linear chains of silicate tetrahedra. Chrysotile and amphibole asbestoses fundamentally differ by the number and shape of the silicate units. These differences can be visually identified from Figures 2.1 and 2.2, which are structure schematics of chrysotile and amphibole, respectively. Chrysotile consists of Si_2O_5 silicate units arranged in double layers and formed into a laminar structure. The chrysotile Si_2O_5 layers are joined by brucite (magnesium hydroxide) layers. This double layered structure is contorted in tubes in which the brucite forms the outer fiber layer. The amphiboles contain silicate as Si_4O_{11} double chains in a banded structure. The chains are united by intercalcated cations and form as solid fibers (Berger and Oesper, 1963; Badolette, 1963; Kover, 1976).

Unlike the synthetic chemicals which usually exhibit unique chemical compositions, the asbestoses are composed of mixed inorganic oxides. The various asbestoses are characterized by ranges of these oxides rather than precise molecular formulas. Table 2.1 below gives the approximate chemical formula for

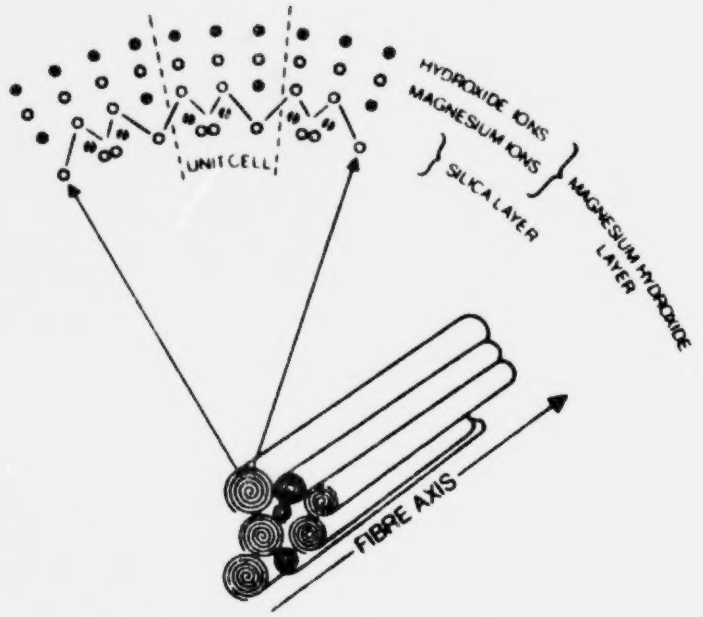
HYDROXIDE IONS
MAGNESIUM IONS
SILICA LAYER
MAGNESIUM HYDROXIDE LAYER
UNIT CELL
FIBRE AXIS

Figure 2.1. Schematic Diagram of the Structure of a Chrysotile Fibre Formed of Several Scrolls of Individual Crystallites (Each scroll is formed from a closely connected double layer having magnesium hydroxide units on its external face and silica units on its inner face. The details of a small section of the scroll show the structure of the double layer and of the unit cell based on $Mg_3(Si_2O_5)(OH)_4$.) (Kover, 1976)

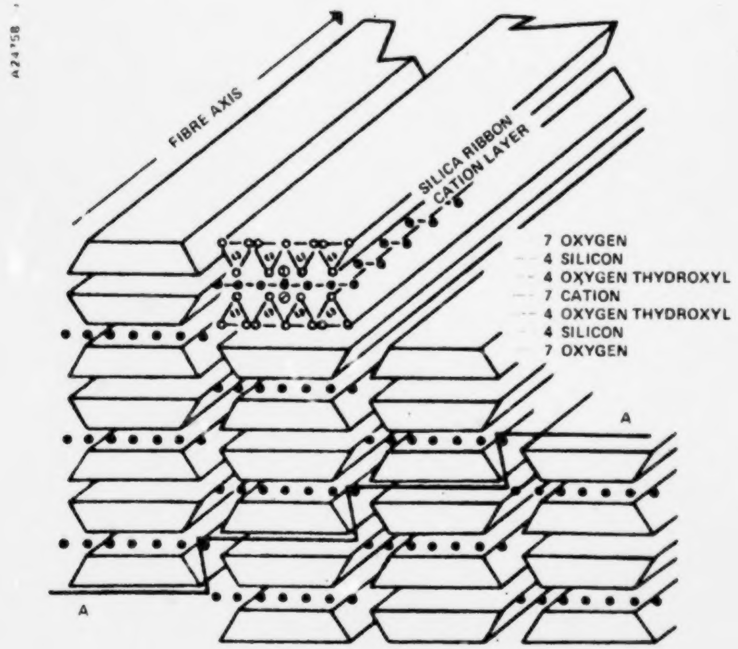
A24158
FIBRE AXIS
SILICA RIBBON
CATION LAYER
7 OXYGEN
4 SILICON
4 OXYGEN THYDROXYL
7 CATION
4 OXYGEN THYDROXYL
4 SILICON
7 OXYGEN
A
A

Figure 2.2. Schematic Diagram of the Crystal Structure of an Amphibole Fiber, Indicating the Unit Cell Based on $X_7Si_8O_{22}$ $(OH)_2$ (The line A-A represents the edge of the preferred cleavage plane along which the fibres will split to form even smaller fibres.) (Kover, 1976)

each of the varieties of asbestos, while Table 2.2 lists the typical ranges of mixed oxide compositions for the asbestoses.

Table 2.1. Approximate Chemical Formula of the Asbestoses (The Asbestos Factbook, 1970)

Chrysotile	$3MgO\ 2SiO_2\ 2H_2O$
Crocidolite	$Na_2O\ Fe_2O_3\ 3FeO\ 8SiO_2\ H_2O$
Amosite	$1.5MgO\ 5.5FeO\ 8SiO_2\ H_2O$
Anthophyllite	$7MgO\ 8SiO_2\ H_2O$
Tremolite	$2CaO\ 5MgO\ 8SiO_2\ H_2O$
Actinolite	$2CaO\ 4MgO\ FeO\ 8SiO_2\ H_2O$

Since asbestos is a metamorphic mineral, its composition reflects the composition of the surrounding minerals and its formation conditions. Therefore, the oxide composition range differs for asbestoses of different geographical origin, as evident from Table 2.3. The asbestoses contain relatively few elements. In addition to silicate and water, they generally contain the oxides of magnesium, calcium, iron, and/or sodium. Aluminum and potassium oxides are sometimes present as trace "impurities." The "impurities" are defined as the oxides which are not accounted in the approximate chemical composition. They can either form part of the polymeric structure or occur as occlusions within the fibers (Berger and Oesper, 1963).

Table 2.4 describes some of the properties important in the commercial uses of asbestos. The properties of asbestos that give it commercial value are

Table 2.2. Chemical Composition of Common Fibrous Silicate Minerals (Kover, 1976)

	Typical ranges, wt-%								
	SiO_2	MgO	FeO	Fe_2O_3	Al_2O_3	CaO	K_2O	Na_2O	H_2O
Chrysotile	38–44	40–43	0–0.8	0.5–4	0.3–0.9	0–1.0	Trace	Trace	13–14
Crocidolite	49–53	0–3	13–20	17–20	0–0.2	0.3–2.7	0–0.4	4–8.5	2.5–4.5
Amosite	49–53	1–7	34–44	-----	-----	-------	0–0.4	Trace	2.5–4.5
Anthophyllite	56–58	28–34	3–12	-----	0.5–1.5	-------	-----	-------	1–6
Actinolite	51–56	15–20	5–15	0–3	1.5–3	10–12	0–0.5	0.5–1.5	1.5–2.5
Tremolite	55–60	21–26	0–4	0–0.5	0–2.5	11–13	0–0.6	0–1.5	0.5–2.5

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Table 2.3. Chemical Composition of Asbestoses from Different Geographic Locations (The Asbestos Factbook, 1970)

Variety and Location	SiO_2 (Silica)	FeO (Ferrous Oxide)	Fe_2O_3 (Ferric Oxide)	Al_2O_3 (Alumina)	MgO (Magnesia)	CaO (Lime)	MnO (Manganese Oxide)	Na_2O (Sodium Oxide)	K_2O (Potassium Oxide)	H_2O- (Combined Water)	H_2O+ (Combined Water)
Chrysotile (Quebec)	40.2	1.0	0.5	2.9	39.9	1.1	0.1	0.1	0.1	0.8	13.4
Chrysotile (So. Rhodesia)	39.7	0.7	0.3	3.2	40.3	1.1	0.3	0.1	0.1	0.6	12.2
Chrysotile (Ural Mts.)	38.1	1.3	1.4	5.0	37.7	2.2	0.1	0.1	0.1	0.8	11.1
Crocidolite (Cape Province)	50.9	20.5	16.9	nil	1.1	1.5	0.1	6.2	0.2	0.2	2.2
Crocidolite (Australia)	52.8	14.9	18.6	0.2	4.6	1.1	Trace	6.0	0.1	0.2	2.8
Crocidolite (Bolivia)	55.7	3.8	13.0	4.0	13.1	1.5	Trace	6.9	0.4	Trace	1.8
Amosite (Transvaal)	49.4	40.6	0.1	nil	6.7	0.7	0.7	0.1	0.2	0.1	1.9
Anthophyllite (Finland)	59.1	6.7	1.0	0.9	29.7	0.1	0.2	0.1	0.1	0.5	2.4
Tremolite (Pakistan)	55.1	2.0	0.3	1.1	25.7	11.5	0.1	0.3	0.2	3.5	0.2
Actinolite (Cape Province)	53.8	25.3	2.0	1.2	4.3	10.2	0.4	0.4	0.1	0.2	2.6

Table 2.4. Physical, Chemical, and Mineralogical Properties of Varieties of Asbestos (Kover, 1976)

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Chemical formula	$Mg_3Si_2O_5(OH)_4$	$Na_2Fe_3Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$Ca_2Mg_5Si_8O_{22}(OH)_2$	$(CaMgFe)_5Si_8O_{22}(OH)_2$
pH	9.2 to 9.8	--	--	Neutral	--	--
Resistance to acids	Poor	Good	--	--	Good	Good
Veining	Cross and slip fibers	Cross fiber	Cross fiber	Slip, mass fiber unoriented and interlacing	Slip or mass fiber	Slip or mass fiber
Color	Green, gray, amber to white	Blue	Gray, yellow to dark brown	Yellowish brown, grayish white	Gray-white, greenish, yellowish, bluish	Greenish
Texture	Soft to harsh, also silky	Soft to harsh	Coarse but somewhat pliable	Harsh	Generally harsh, sometimes soft	Harsh
Luster	Silky	Silky to dull	Vitreous, somewhat pearly	Vitreous to pearly	Silky	Silky
Hardness[a]	2.5 to 4.0	4	5.5 to 6.0	5.5 to 6.0	5.5	6±
Flexibility	High	Good	Good	Poor	Poor	Poor
Spinnability	Very good	Fair	Fair	Poor	Poor	Poor
Tensile strength, lb. in.^{2}	824,000 max.	876,000 max.	16,000 to 90,000	4,000 and less	1,000 to 8,000	1,000 and less
Fusion point, °F	2,770	2,180	2,550	2,675	2,400	2,540
Specific heat, Btu/lb.°F	0.266	0.201	0.193	0.210	0.212	0.217

[a] Working Scale of Hardness: 1 - very easily scratched by fingernail, and has greasy feel to the hand; 2 - easily scratched by fingernail; 3 - scratch by brass pin or copper coin; 4 - easily scratched by knife; 5 - scratch with difficulty with knife; 6 - easily scratched by file; 7 - little touched by file, but will scratch window glass. All harder than 7 will scratch window glass.

Table 2.4. Physical, Chemical, and Mineralogical Properties of Varieties of Asbestos (Cont'd)

Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite	Actinolite
Electric charge	Positive	Negative	Negative	Negative	Negative	Negative
Filtration properties	Slow	Fast	Fast	Medium	Medium	Medium
Specific gravity	2.4 to 2.6	3.2 to 3.3	3.1 to 3.25	2.85 to 3.1	2.9 to 3.2	3.0 to 3.2
Cleavage	010 perfect	110 perfect	110 perfect	110 perfect	110 perfect	110 perfect
Optical properties	Biaxial positive, extinction parallel	Biaxial ±, extinction inclined	Biaxial positive, extinction parallel	Biaxial positive, extinction parallel	Biaxial negative, extinction inclined	Biaxial negative, extinction inclined
Refractive index	1.50 to 1.55	1.7 pleochroic	1.64±	1.61±	1.61±	1.63± weakly pleochroic
Resistance to destruction by heat	Good, brittle at high temperatures	Poor, fuses	Good, brittle at high temperatures	Very good	Fair to good	--
Temperature at ignition loss,° F	1,800	1,200	1,600 to 1,800	1,800	1,800	--
Magnetic content,%	0.0 to 5.0	3.0 to 5.9	0	0	0	--
Crystal structure	Fibrous and asbestiform	Fibrous	Prismatic, lamellar to fibrous	Prismatic, lamellar to fibrous	Long and thin columnar to fibrous	Long and thin columnar to fibrous
Crystal system	Monoclinic and orthorhombic	Monoclinic	Monoclinic	Orthorhombic	Monoclinic	Monoclinic
Mineralogical structure	In veins of serpentine, etc.	Fibrous in iron stones	Lamellar, coarse to fine fibrous and asbestiform	Lamellar, fibrous asbestiform	Long, prismatic and fibrous aggregates	Reticycled long prismatic crystals and fibers
Mineral association	In altered peridotite adjacent to serpentine and limestone near contact with basic igneous rocks	Iron rich silicious argillite in quartzose schists	In crystalline schists, etc.	In crystalline schists and gneisses	In Mg limestones as alteration product of magnesian rocks, metamorphic and igneous rocks	In limestones and in crystalline schists

its fibrous structure, the great strength of its fibers, and its resistance to high temperatures and to certain types of chemical attack.

Chrysotile asbestos excels commercially due to its fineness of fiber, high flexibility, good heat resistance, general workability, and ample supply. The longer fibers can be spun easily into textile materials. However, chrysotile degrades faster than the amphiboles in water, acids, or alkalis. This results from the solubility and reactivity of the brucite. While amphiboles lose only ca. 9% of their weight in 4N HCl after eight hours at 100°C, chrysotile looses all magnesium hydroxide (60% of its weight) after only one hour in 1 N HCl at 95°C (Berger and Oesper, 1963). When chrysotile is extracted by the Soxhlet procedure for four hours with aqueous alkali (pH 10.33), it loses a high percentage of magnesium ion and yields magnesium silicate. Crocidolite, when treated by the same conditions, will leach only 4% silica and 6% sodium (Berger and Oesper, 1963). Because crocidolite and amosite fibers are highly acid-resistant, they are particularly valuable for use in chemical plant applications. Anthophyllite asbestos and tremolite asbestos fibers are too brittle to be spun or used as fibrous reinforcements but, because of their resistance to attack by certain chemicals, are used for filtering purposes in chemical processing plants and in laboratories.

Since asbestos is often used in the manufacture of insulation for electrical equipment, its electrical conductance is an important property. Its conductance is related to the magnetite (Fe_3O_4) content. As the content of this impurity increases, the asbestos conductance also increases (Berger and Oesper, 1963).

The thermal stability is limited by asbestos metamorphosis to other mineral forms. The fusion points listed in Table 2.4 are not melting points for the asbestoses, but correspond to the fusion temperature of the metamorphic products. Chrysotile, for example, is thermally transformed to the minerals olivine or enstatite at a rate dependent upon time and temperature. The transformation may be important to assess some environmental losses for certain uses, such as in brake linings (Berger and Oesper, 1963).

2.2 Asbestos Grading

Asbestos is graded by fiber length. It is not commonly graded by mineralogical content or other properties. The Quebec Standard for chrysotile is the most important, because most asbestos consumed in the U.S. is graded by this system. The Quebec Standard measures the distribution of fibers after sieving a 16 ounce sample through a system constructed of four boxes: three screens and a "pan" for fines:

Box Number	Screen Opening	Diameter of Wire
1	0.500"	0.105"
2	0.187"	0.063" (4 mesh)
3	0.053"	0.047" (10 mesh)

Asbestos fibers are graded in nine groups: Groups No. 1 and 2 are hand-cobbled crudes and the remainder are milled fibers. Group No. 1 is basically 3/4" staple and longer fibers, which makes the best spinning grade. Group No. 2 includes spinning fibers of lower quality. The milled fibers are grouped according to the box distributions listed in Table 2.5 (Berger and Oesper, 1963; The Asbestos Factbook, 1970).

Other grading systems are also used for chrysotile and the amphibole asbestoses. They also grade fibers by length. U.S. mined asbestos basically

Table 2.5. Chrysotile Grades by the Quebec Standard Test
(The Asbestos Factbook, 1970)

Standard Grade Designation	Fiber Description
Group No. 1, Crude No. 1	- consists basically of crude 3/4" staple and longer
Group No. 2, Crude No. 2	- consists basically of crude 3/8" staple up to 3/4"
Group No. 2, Crude run-of-mine	- consists basically of unsorted crudes
Group No. 2, Crudes sundry	- consists of crudes other than above specified
Groups No. 3 through No. 9	- are "Milled Asbestos"

Guaranteed Minimum Shipping Test
(Distribution of 16 oz. of Fibers)

		Box 1	Box 2	Box 3	Pan (fines)
Group No. 3:	3F	10.5	3.9	1.3	0.3
	3K	7.0	7.0	1.5	0.5
	3R	4.0	7.0	4.0	1.0
	3T	2.0	8.0	4.0	2.0
	3Z	1.0	9.0	4.0	2.0
Group No. 4:	4A	0.0	8.0	6.0	2.0
	4D	0.0	7.0	6.0	3.0
	4H	0.0	5.0	8.0	3.0
	4J	0.0	5.0	7.0	4.0
	4K	0.0	4.0	9.0	3.0
	4M	0.0	4.0	8.0	4.0
	4R	0.0	3.0	9.0	4.0
	4T	0.0	2.0	10.0	4.0
	4Z	0.0	1.5	9.5	5.0
Group No. 5	5D	0.0	0.5	10.5	5.0
	5K	0.0	0.0	12.0	4.0
	5M	0.0	0.0	11.0	5.0
	5R	0.0	0.0	10.0	6.0
	5Z	0.0	0.0	8.6	7.4

Table 2.5. Chrysotile Grades by the Quebec Standard Test (Cont'd)

		Box 1	Box 2	Box 3	Pan (fines)
Group No. 6	6D	0.0	0.0	7.0	9.0
Group No. 7	7D	0.0	0.0	5.0	11.0
	7F	0.0	0.0	4.0	12.0
	7H	0.0	0.0	3.0	13.0
	7K	0.0	0.0	2.0	14.0
	7M	0.0	0.0	1.0	15.0
	7R	0.0	0.0	0.0	16.0
	7T	0.0	0.0	0.0	16.0
	7W	0.0	0.0	0.0	16.0
Group No. 8	8S	under 50 lbs/cubic foot loose measure			
	8T	under 76 lbs/cubic foot loose measure			
Group No. 9	9T	over 75 lbs/cubic foot loose measure			

follows the Quebec Standard. Table 2.6 describes the modifications used for Arizona mined asbestos.

2.3 Major Uses of the Asbestoses

The following discussion briefly describes the major uses for the asbestoses and the reasons why they are used. Market input/output data concerning the quantities consumed according to use and grade are given in Section 4.0.

2.3.1 Chrysotile

Chrysotile dominates the asbestos consumed in total quantity, value, and number of products. It accounts for about 95% of all the asbestos commercially consumed.

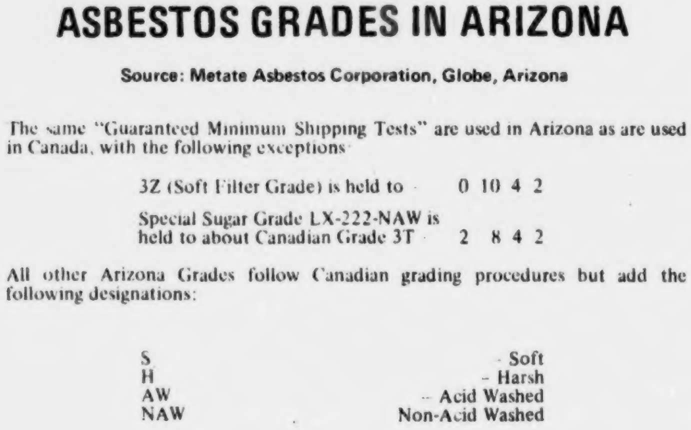
(a) Asbestos Textiles

The long chrysotile fibers (Grades No. 1, 2, and 3) are predominantly used for textile manufacture. The textile products can eventually be marketed as textiles such as safety clothing, drapes and curtains, wicks, etc. or they can be further processed with resins and other additives in the manufacture of friction materials, gaskets, laminated plastics, etc. (Kover, 1976; Hendry, 1965; The Asbestos Factbook, 1970; Clifton, 1975).

(b) Asbestos Cement

Medium sized chrysotile fiber (Groups No. 4 to 7) dominate in production of asbestos cement products (pipe and sheet). Asbestos cement products account for the major portion of the asbestos consumption, both in tonnage of fiber and market value. The properties which contribute to its commercial position include fiber length and tensile strength (Kover, 1976; Carton, 1974; Berger and Oesper, 1963; Clifton, 1976).

Table 2.6. Modifications in Grading American Mined Asbestos
(The Asbestos Factbook, 1970)



ASBESTOS GRADES IN ARIZONA

Source: Metate Asbestos Corporation, Globe, Arizona

The same "Guaranteed Minimum Shipping Tests" are used in Arizona as are used in Canada, with the following exceptions:

3Z (Soft Filter Grade) is held to	0	10	4	2
Special Sugar Grade LX-222-NAW is held to about Canadian Grade 3T	2	8	4	2

All other Arizona Grades follow Canadian grading procedures but add the following designations:

S	- Soft
H	– Harsh
AW	-- Acid Washed
NAW	Non-Acid Washed

(c) Asbestos Paper and Felt

Properties for which chrysotile is used in this product segment include its capacity for heat and electrical insulation, its chemical and thermal stability, its strength and flexibility (Kover, 1975; Carton, 1974; Hendry, 1965). Chrysotile grades from 3 to 7 are predominantly used (Berger and Oesper, 1963; Clifton, 1975).

(d) Composition Materials

The composition materials include plastics, asbestos-vinyl and asbestos-asphalt products, coatings, and compounds. Chrysotile is added to these products generally as a filler and reinforcement medium (Modic and Barsness, 1965; Seymour, 1968; Grove and Rosato, 1967). The longer fibers (including Grades No. 1 and 2) are used in the production of high grade laminated plastics. The short fibers (Grades No. 4 and shorter) dominate in the manufacture of most other composition materials (Clifton, 1975; Berger and Oesper, 1963). Although the quantity of fibers used in these products is large (the second largest consumption of fibers), the low value of the short fibers results in a low commercial value for asbestos used in this market segment.

(e) Friction Materials

The properties for which asbestos is used in friction materials include its capacity for thermal stability, its ability to act as a reinforcing agent, as a filler, for the regulation or inhibition of resin flow, its lower abrasion than other fillers of its price range, and its dispersion of metal chips and other particulates (Hendry, 1965). While the fiber lengths of Grades No. 4 to 7 dominate the friction materials, some longer fibers are also used (Clifton, 1975).

(f) Packing and Gaskets

Chrysotile use in packings and gaskets is accounted for by its strength, resiliency, durability, toughness, and thermal stability (Hendry, 1965; Kover, 1976). Fiber length predominantly ranges from Grades No. 4 to 7, although some Grades 1 through 3 are also consumed (Clifton, 1975; Berger and Oesper, 1963; SRI, 1974).

2.3.2 Crocidolite

Crocidolite fibers are shorter and more brittle than chrysotile but have a slightly higher tensile strength. Crocidolite is principally consumed for the manufacture of asbestos cement products (Kover, 1976; Clifton, 1976). While it can be spun into fibers, its spinnability is not equivalent to chrysotile. Longer crocidolite fibers are sometimes mixed with chrysotile for textile production (Berger and Oesper, 1963). It is used as replacement for chrysotile fibers in some laggings, insulations, filter media, and packings exposed to corrosive (acid or alkali) substances (Fisher, 1967; Hendry, 1965; Kover, 1976). Long crocidolite fibers are also consumed in asbestos boards and papers (Berger and Oesper, 1963).

2.3.3 Amosite

Amosite has lower tensile strength than chrysotile or crocidolite by more than an order of magnitude. It is consumed mainly in asbestos cement products. Other major uses are in various thermal insulations, including pipe and boiler coverings, bulkhead linings in ships, and 85% magnesia insulation (Hendry, 1965; Kover, 1976).

2.3.4 Tremolite and Actinolite

Both tremolite and actinolite asbestoses are of low tensile strength and are brittle. They have only minor commercial use. They are primarily consumed as cheap fillers and as filtering mediums. Tremolite is sometimes purified by acid treatment for special filtering purposes (Kover, 1976; Hendry, 1965).

2.3.5 Anthophyllite

Anthophyllite asbestos is also of minor commercial value. It is mainly used as a filler in rubber, plastics, adhesives, and asbestos cement products (Kover, 1976; Hendry, 1965; Clifton, 1975).

3.0 DESCRIPTION OF THE ASBESTOS INDUSTRY

3.1 Industry Structure

Figure 3.1 below is a simple illustration showing the movement of asbestos within the asbestos industry.

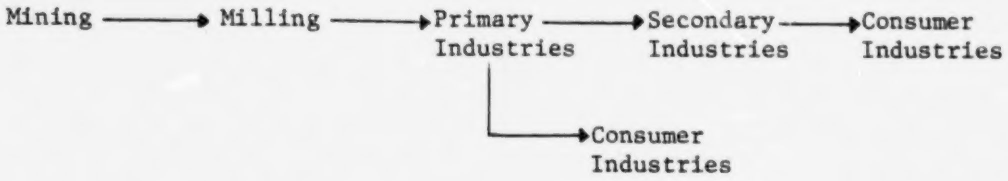


Figure 3.1. Asbestos Industry Structure

The following definitions have been adopted (Daly *et al.*, 1976):

Primary Industries: those industries that start the manufacturing process with *raw* asbestos fiber and modify the fiber to produce an intermediate product (to be further processed or fabricated) or a finished product.

Secondary Industries: those industries that continue the manufacturing process with an *intermediate* asbestos product (one in which the fiber has previously been modified in a primary industry), and further process, modify, or fabricate it to produce either another intermediate product (to be further processed or fabricated) or a finished product.

Consumer Industries: those industries that purchase a finished asbestos-containing product (from a primary or secondary industry), and apply, install, erect, or consume the asbestos-containing product without further physical modification of the product.

This classification is depicted in Figure 3.2, which categorizes the various end uses by products.

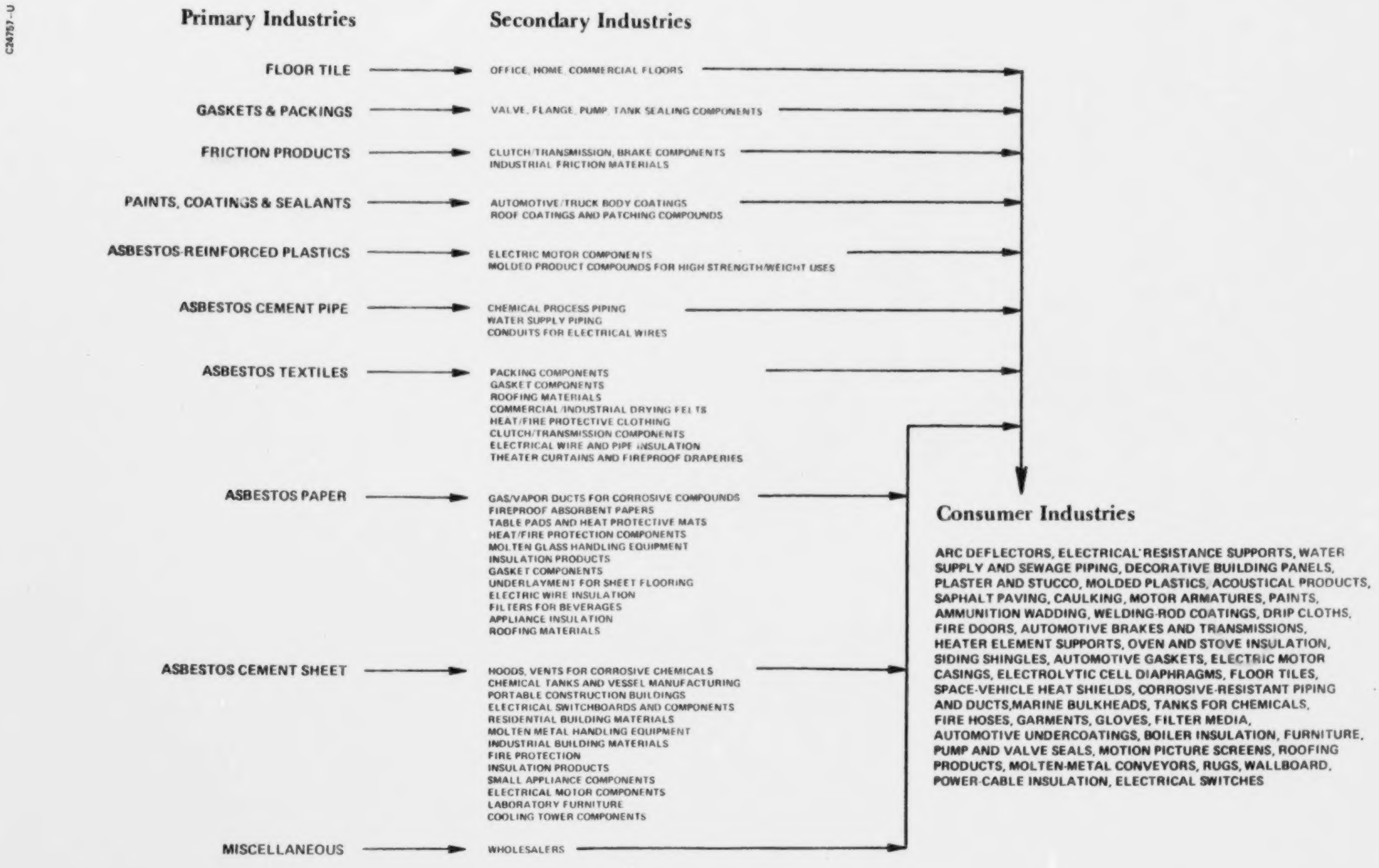

C24757-U
Primary Industries
Secondary Industries
FLOOR TILE
OFFICE, HOME, COMMERCIAL FLOORS
GASKETS & PACKINGS
VALVE, FLANGE, PUMP, TANK SEALING COMPONENTS
FRICTION PRODUCTS
CLUTCH/TRANSMISSION, BRAKE COMPONENTS
INDUSTRIAL FRICTION MATERIALS
PAINTS, COATINGS & SEALANTS
AUTOMOTIVE/TRUCK BODY COATINGS
ROOF COATINGS AND PATCHING COMPOUNDS
ASBESTOS-REINFORCED PLASTICS
ELECTRIC MOTOR COMPONENTS
MOLDED PRODUCT COMPOUNDS FOR HIGH STRENGTH/WEIGHT USES
ASBESTOS CEMENT PIPE
CHEMICAL PROCESS PIPING
WATER SUPPLY PIPING
CONDUITS FOR ELECTRICAL WIRES
ASBESTOS TEXTILES
PACKING COMPONENTS
GASKET COMPONENTS
ROOFING MATERIALS
COMMERCIAL/INDUSTRIAL DRYING FELTS
HEAT/FIRE PROTECTIVE CLOTHING
CLUTCH/TRANSMISSION COMPONENTS
ELECTRICAL WIRE AND PIPE INSULATION
THEATER CURTAINS AND FIREPROOF DRAPERIES
ASBESTOS PAPER
GAS/VAPOR DUCTS FOR CORROSIVE COMPOUNDS
FIREPROOF ABSORBENT PAPERS
TABLE PADS AND HEAT PROTECTIVE MATS
HEAT/FIRE PROTECTION COMPONENTS
MOLTEN GLASS HANDLING EQUIPMENT
INSULATION PRODUCTS
GASKET COMPONENTS
UNDERLAYMENT FOR SHEET FLOORING
ELECTRIC WIRE INSULATION
FILTERS FOR BEVERAGES
APPLIANCE INSULATION
ROOFING MATERIALS
ASBESTOS CEMENT SHEET
HOODS, VENTS FOR CORROSIVE CHEMICALS
CHEMICAL TANKS AND VESSEL MANUFACTURING
PORTABLE CONSTRUCTION BUILDINGS
ELECTRICAL SWITCHBOARDS AND COMPONENTS
RESIDENTIAL BUILDING MATERIALS
MOLTEN METAL HANDLING EQUIPMENT
INDUSTRIAL BUILDING MATERIALS
FIRE PROTECTION
INSULATION PRODUCTS
SMALL APPLIANCE COMPONENTS
ELECTRICAL MOTOR COMPONENTS
LABORATORY FURNITURE
COOLING TOWER COMPONENTS
MISCELLANEOUS
WHOLESALERS
Consumer Industries
ARC DEFLECTORS, ELECTRICAL RESISTANCE SUPPORTS, WATER SUPPLY AND SEWAGE PIPING, DECORATIVE BUILDING PANELS, PLASTER AND STUCCO, MOLDED PLASTICS, ACOUSTICAL PRODUCTS, SAPHALT PAVING, CAULKING, MOTOR ARMATURES, PAINTS, AMMUNITION WADDING, WELDING-ROD COATINGS, DRIP CLOTHS, FIRE DOORS, AUTOMOTIVE BRAKES AND TRANSMISSIONS, HEATER ELEMENT SUPPORTS, OVEN AND STOVE INSULATION, SIDING SHINGLES, AUTOMOTIVE GASKETS, ELECTRIC MOTOR CASINGS, ELECTROLYTIC CELL DIAPHRAGMS, FLOOR TILES, SPACE-VEHICLE HEAT SHIELDS, CORROSIVE-RESISTANT PIPING AND DUCTS,MARINE BULKHEADS, TANKS FOR CHEMICALS, FIRE HOSES, GARMENTS, GLOVES, FILTER MEDIA, AUTOMOTIVE UNDERCOATINGS, BOILER INSULATION, FURNITURE, PUMP AND VALVE SEALS, MOTION PICTURE SCREENS, ROOFING PRODUCTS, MOLTEN-METAL CONVEYORS, RUGS, WALLBOARD, POWER-CABLE INSULATION, ELECTRICAL SWITCHES

Figure 3.2. Asbestos Products Industry (Daly *et al.*, 1976)

The first industry segment to come into contact with the asbestos is, of course, the mining segment. As far as the United States is concerned, however, this predominately occurs in Canada. From 1971 to 1975, between 80-85% of the asbestos consumed domestically was imported (see Sections 4.3 and 4.4); and of the imported asbestos, nearly 96% originated in Canada (Clifton, 1975). The milling segment of the industry is very closely connected to the mining segment because mills are usually located in close geographical proximity to the mines and, in general, the mines and mills are owned and operated by the same parent corporation. American mining and milling production is discussed in Section 5.1.

The interesting relationship is, however, the relationship between the mining segment of the industry and the primary industries, the product manufacturers who initially fabricate asbestos products. Table 3.1 lists the captive fiber sources in Canada and in the U.S. for the major domestic asbestos products manufacturing firms. Twenty of the largest U.S. asbestos products manufacturers are listed in Table 3.2. When Tables 3.1 and 3.2 are compared, it can be seen that four corporations (Johns-Manville, Raybestos-Manhattan, Jim Walter, and ASARCO) not only control large mining interests in Canada, but also control nearly 35% of the American asbestos products market.

According to the 1967 U.S. Census of Manufacturers, 81 firms operating 138 establishments were involved in asbestos products manufacturing (SIC 3292; this does not include asbestos paper-making establishments). The 1972 Census of Manufacturers lists 142 establishments for SIC 3292. When the asbestos papermakers are included, it is estimated that approximately 85 firms are presently engaged in asbestos products manufacture (SRC estimate). In evaluating the asbestos products manufacturing industry, it is possible to arrive at the

Table 3.1. Captive Fiber Sources for the Major American Asbestos Product Manufacturing Firms (Igwe, 1974; Asbestos Magazine, Dec. 1975)

Company	Mine (Company)	Fiber-Producing Capacity (short tons/year)
	Canadian Mines	
ASARCO	Lake Asbestos of Quebec, Ltd.	150,000
Johns-Manville Products Corp.	Canadian Johns-Manville Co., Ltd.	835,000
Jim Walter Corp.	Carey-Canadian Mines, Ltd.	200,000
Raybestos-Manhattan, Inc.	Cassiar Asbestos Corp. (partial interest)	110,000
General Dynamics Corp.	Asbestos Corp., Ltd. (54% interest)	500,000
	American Mines	
Atlas Asbestos Co.	Atlas Asbestos Co.	25,000
Union Carbide Corp.	Union Carbide Mines	10,000
Johns-Manville Products Corp.	Coalings Asbestos Co.	(closed at present)

Table 3.2. Twenty of the Largest U.S. Asbestos Product Manufacturers (Economic Information Systems, 1976; Igwe, 1974; SRC Estimates)

Company	Estimated 1975 Asbestos-Product Sales ($ millions)	Approximate Percentage of the U.S. Market
1. Johns-Manville Corp.	240	18.0
2. Raybestos-Manhattan, Inc.	140	10.5
3. GAF Corp.	114	8.5
4. Bendix Corp.	72.5	5.5
5. Jim Walter Corp. (Celotex)	71	5.5
6. Armstrong Cork Co.	60	4.5
7. Illinois Central Industries (Abex Corp.)	60	4.5
8. Flintkote Co.	50	3.5
9. Asten-Hill Mfg. Co.	40.5	3.0
10. H.K. Porter Co.	37.6	3.0
11. Certain-Teed Corp.	33.1	2.5
12. Nicolet Industries	30.7	2.0
13. Kentile Floors Inc.	29.5	2.0
14. National Gypsum Co.	27.1	2.0
15. Royal Industries	24.5	2.0
16. Uvalde-Rock-Asphalt Co.	21.6	1.5
17. Sabine Industries	21.6	1.5
18. American Asbestos Textile	15.0	1.0
19. ASARCO Inc. (Cement Asbestos Products)	13.0	1.0
20. Gatke Corp.	11.6	1.0

conclusion that the industry may be dominated by several giant firms. From Table 3.2 it can be seen that the six largest firms control over 50% of the market. It should also be noted that the larger asbestos-based manufacturing firms are generally diversified into other product lines. Table 3.3 shows the percentage of some major manufacturers' product lines that are related to asbestos.

Table 3.3. Asbestos-Based Activity of Some Major Asbestos-Manufacturing Companies (Igwe, 1974; SRC Estimates)

Company	Estimated Annual Sales ($ millions)	Percent of Product Line Related to Asbestos
American Biltrite Rubber Co.	161	5
The Flintkote Co.	441	12
GAF Corp.		5
Johns-Manville Corp.	800	30
National Gypsum Co.	519	5
Jim Walter Corp.	880	8

3.2 Types of Plants

Asbestos products manufacturing plants are characterized by a high degree of specialization. The typical plant (especially of the minor manufacturers) is apt to be a single-product operation whose product is geared to service a specific industry. Table 3.4 lists the general statistics for

Table 3.4. Industry Specialization and Primary Product Class Specialization for Asbestos Product Producing Establishments: 1972 (SIC 3292) (1972 Census of Manufacturers, U.S. Bureau of the Census)

	Establishments	Establishments with 75% or More Specialization
Entire Industry	142	127
Primary Product Class		
Friction Materials	23	21
Asbestos-Cement Shingles and Clapboard	7	6
Vinyl Asbestos Floor Tile	18	17
Asbestos and Asbestos-Cement Products	55	42

establishment specialization in 1972. In Table 3.4 the measures of plant specialization are shown as: (1) industry specialization - the ratio of primary product shipments to total product shipments (primary plus secondary) and (2) product class specialization - the ratio of the largest primary product class shipments to total product shipments (primary plus secondary) for the establishment.

A survey of selected facilities shows that nearly all the large plants employing in excess of 100 workers belong to the major firms within the industry, such facilities also often generating relatively minor proportions of non-asbestos products (Igwe, 1974).

It is fair to state that the asbestos manufacturing industry in the United States is very mature, with most of the larger plants well over 25 years old and employing well-established technologies. For instance, asbestos-cement pipe manufacture was introduced in the United States about 1928 by the Johns-Manville Corporation at its Waukegan, Illinois, plant. Except for incorporation of sophisticated controls and materials handling systems, it is doubtful whether the technology, similar in principle to that employed in the manufacture of flat or corrugated sheeting, has changed to any fundamental extent since then. Similar comments may be applied to the manufacture of vinyl asbestos tiles (Igwe, 1974).

3.3 Numerical and Percentage Distribution of Plants, Employees, and Production

The numerical distribution of the establishments by size (expressed in terms of the number of employees) as given by the 1972 Census of Manufacturers is shown in Table 3.5. Total employment as a function of establishment size and total value of shipments as a function of establishment size for asbestos products manufacturing are given in Table 3.6.

A comparison of Tables 3.5 and 3.6 shows that whereas establishments with less than 100 employees account for 53.4% of the number of asbestos products manufacturing establishments, these facilities employ only 7.8% of the work force. The relative minor contributions of the "less-than-100-employees" facilities are further illustrated when Table 3.5 is compared to Table 3.6. The industry segment with less than 100 employees per establishment contributes only 6.1% of the shipment values of asbestos products. The economic punch appears clearly to rest with the major manufacturing units.

There is the additional consideration that, for a given asbestos product, the manufacturing equipment tends to be of a given standard capacity.

Table 3.5. Asbestos Products Manufacture: Distribution of Plant Sizes (1972 Census of Manufacturers (SIC 3292), U.S. Bureau of the Census)

Average Number of Employees	Total Number of Establishments	Percent of Total
1 to 4	12	8.5
5 to 9	20	14.0
10 to 19	13	9.1
20 to 49	16	11.3
50 to 99	15	10.5
100 to 249	40	28.2
250 to 499	19	13.4
500 to 999	5	3.5
1000 to 2499	2	1.4
Total	142	

Table 3.6. Asbestos Products Manufacturing: Total Value of Shipments as a Function of Size of Facilities (1972 Census of Manufacturers (SIC 3292), U.S. Bureau of the Census)

Average Number of Employees	Value of Shipments ($ millions)	Percent of Total
1 to 4	0.7	--
5 to 9	4.9	0.5
10 to 19	7.4	0.8
20 to 49	15.8	1.6
50 to 99	30.7	3.2
100 to 249	246.8	25.6
250 to 499	255.6	26.5
500 to 999	201.5	20.9
1000 to 2499	200.0*	20.8
Total	963.4	

* SRC Estimate

Differences in plant capacities are therefore determined approximately by the number of installed machines, and capacity differences therefore occur in multiples of one standard machine capacity (Igwe, 1974).

4.0 MARKET INPUT/OUTPUT DATA

The salient statistics for asbestos are graphed in Figure 4.1, which covers the period from 1940 to 1976. Import and export data shown in Figure 4.1 represent shipments of unmanufactured asbestos only.

4.1 Mine Production

Table 4.1 lists the domestic and world mine productions from 1965 to 1976. U.S. mines shipped only 75% as much asbestos in 1974 as in 1973 and only 66% as much in 1975 as in 1973. The exact total output of 112,533 tons in 1974 was valued at $13,759,000 (Clifton, 1975).

Only four states produce asbestos: California, with 53% of the 1974 total, was the leader, followed in order by Vermont, Arizona, and North Carolina. The California segment of the asbestos industry has led the sharp decline in U.S. production. The closing, in early 1974, of Johns-Manville's (Coalings Asbestos Co.) mine was followed by the closing of H.K. Porter's (Pacific Asbestos Corp.) mine. These mine closures led to production of only 57% of the 1973 California state total, and only 55% of the 1973 dollar value of the fiber was realized (Clifton, 1975). The H.K. Porter mine was sold in October, 1975, to Calaveras Asbestos Ltd. and began operation in 1976 (Clifton, 1977).

All of the American mines produce the chrysotile variety of asbestos except the North Carolina mines which produce the anthophyllite variety. In total, the American mines produce approximately 15% of the asbestos used in the United States. The remainder is imported, mostly from Canada (see Section 4.3).

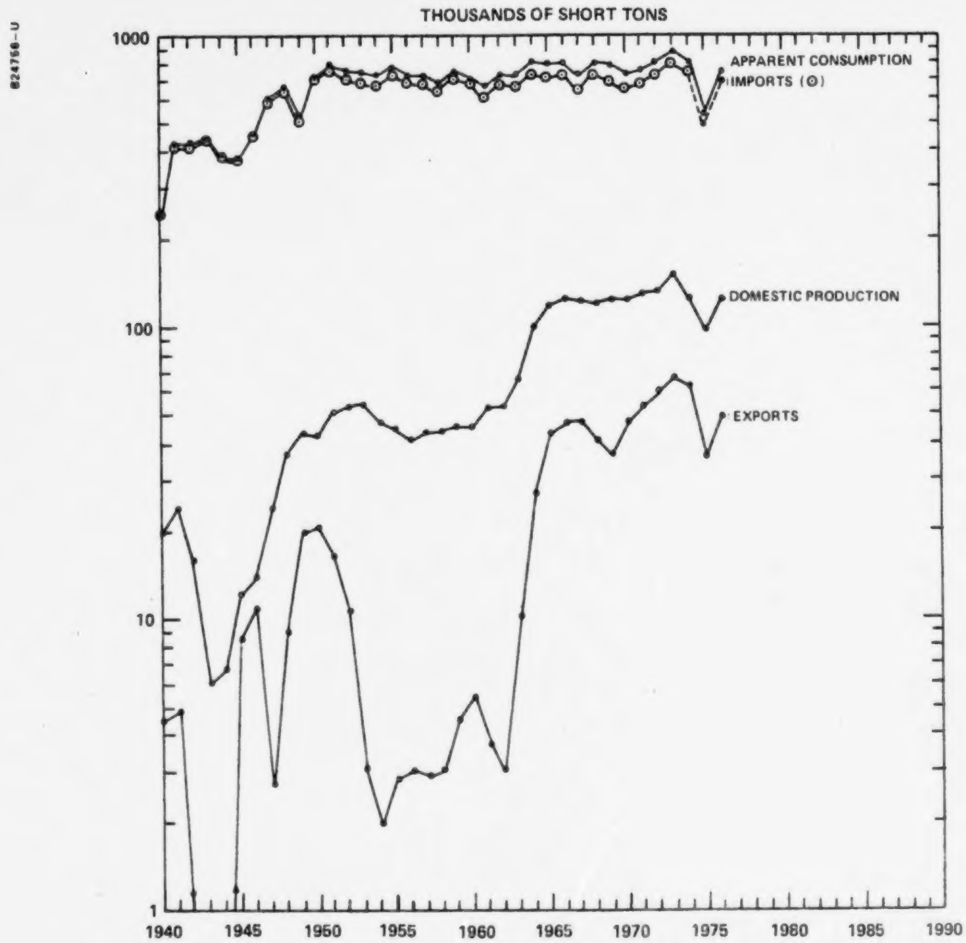


Figure 4.1. Asbestos - Salient Statistics (SRI, 1974; Clifton, 1977; U.S. Bureau of the Census, 1975 a, b)

Table 4.1. Mine Production of Asbestos (Clifton, 1977)

(Thousand short tons)

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
World mine production:												
United States	118	126	123	121	126	125	131	132	150	113	99	115
Rest of world	2,984	3,149	3,084	3,170	4,042	3,672	3,816	4,050	4,448	4,423	4,410	4,885
Total	3,102	3,275	3,207	3,291	4,168	3,797	3,947	4,182	4,598	4,536	4,509	5,000

4.2 Exports

Table 4.2 below lists the American export of asbestos (unmanufactured) from 1965 to 1975.

Table 4.2. U.S. Export of Asbestos (Unmanufactured) for 1965 - 1976 (Clifton, 1977; U.S. Bureau of the Census, 1975 b)

Year	Asbestos Export in Thousands of Short Tons
1976	47
1975	35
1974	62
1973	66
1972	59
1971	54
1970	47
1969	36
1968	41
1967	47
1966	47
1965	43

Tables 4.3a and 4.3b list the countries to which the exported asbestos (unmanufactured) was shipped in 1975 and in the first half of 1976, respectively, and the amounts shipped to each country. Unmanufactured asbestos includes asbestos fibers, not further processed than beaten, washed or graded to length and asbestos waste and refuse. Table 4.4 lists U.S. exports, by country, of asbestos manufactured products in 1975.

In 1975 U.S. exports of unmanufactured asbestos amounted to only 6.5% of the quantity of U.S. imports, while in 1974 the figure was only 8.1%. On the other hand, the dollar value of U.S. exports of manufactured asbestos products was nearly three times higher than the dollar value of U.S. imports of manufactured asbestos products.

Table 4.3a. U.S. Export -- By Country -- of Asbestos (Unmanufactured) in 1975 (U.S. Bureau of the Census, 1975 b)

	Net Quantity (Short Tons)	Value (Dollars)
2764015 Asbestos fibers, not further processed than beaten, washed, or graded to length		
Canada	1,567	682,546
Mexico	6,881	2,349,846
Brazil	699	261,080
Belgium	463	140,181
France	206	204,242
West Germany	937	335,709
Rumania	494	101,420
Iran	721	252,817
Singapore	1,137	523,255
Japan	1,334	936,115
Other Countries	734	279,895
Total	15,173	6,067,106
2764030 Asbestos waste and refuse		
Canada	3,629	188,856
Mexico	5,109	1,151,572
Colombia	706	124,078
Venezuela	391	70,978
Brazil	115	67,123
United Kingdom	815	131,681
France	458	101,436
West Germany	723	202,087
Italy	120	72,414
Iran	203	78,240
Singapore	615	577,569
Japan	3,842	700,350
Egypt	104	64,558
Other Countries	2,918	460,943
Total	19,748	3,991,885

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*U. S. Bureau of the Census, 1975b

Table 4.3b. U.S. Export -- By Country -- of Asbestos (Unmanufactured) from January, 1976, to June, 1976 (U.S. Bureau of the Census, 1976 b)

2764015 Asbestos fibers, not further processed than beaten, washed, or graded to length

	Net Quantity (Short Tons)	Value (Dollars)
Canada	448	161,298
Mexico	4,883	1,283,987
Venezuela	119	40,302
Brazil	63	41,106
United Kingdom	41	32,000
The Netherlands	298	63,953
Belgium	328	76,115
East Germany	177	130,190
Greece	126	33,840
Rumania	371	101,135
Iran	140	39,033
Thailand	1,320	527,987
Indonesia	900	284,150
Taiwan	300	116,350
Japan	1,532	631,900
Algeria	840	292,428
Other Countries	595	104,760
Total	12,481	3,960,534

2764030 Asbestos waste and refuse

Canada	255	63,389
Mexico	5,430	1,113,082
Colombia	445	80,832
Venezuela	231	36,805
Brazil	378	77,447
United Kingdom	613	114,365
East Germany	400	209,904
Spain	120	57,831
Italy	49	54,279
Rumania	400	76,000
United Arab Emirants	192	125,195
Korean Republic	1,500	348,000
Japan	3,507	546,306
Algeria	760	57,054
Libya	149	101,058
Other Countries	646	158,559
Total	15,075	3,220,106

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*U. S. Bureau of the Census, 1976b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975 *

6618310 Asbestos-cement shingles and clapboard	Net Quantity (Pounds)	Value (Dollars)
Canada	669,126	142,466
United Kingdom	589,890	109,149
West Germany	17,778,767	2,977,698
Italy	7,205,759	943,314
Saudi Arabia	228,577	78,228
Japan	234,704	66,185
Other Countries	1,847,108	331,776
Total	28,553,931	4,648,816
6618320 Articles of asbestos-cement or of fiber-cement except asbestos cement shingles and clapboard		
Canada	21,936,513	3,867,321
Mexico	487,372	138,980
Salvador	455,804	64,879
Panama	5,266,390	715,851
Brazil	134,606	70,184
Sweden	305,303	375,555
West Germany	102,004	87,175
Iran	265,941	79,733
Saudi Arabia	4,511,035	999,724
Indonesia	33,478	161,793
Philipine Republic	360,441	70,893
Japan	418,104	242,323
The Pacific Islands	320,865	71,806
Algeria	2,094,038	185,964
Republic of South Africa	116,300	73,093
Other Countries	1,096,502	422,609
Total	37,904,696	7,627,883
6638105 Asbestos gaskets		
1 Canada	172,100	500,993
Jamaica	32,955	98,785
Iran	39,551	68,213
Saudi Arabia	91,663	202,404
Republic of South Africa	14,105	79,183
Other Countries	184,962	660,608
Total	535,336	1,610,186

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*U. S. Bureau of the Census, 1975b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638115 Asbestos packing		
2 Canada	1,042,869	1,896,802
Mexico	393,093	291,741
Guatemala	25,828	68,294
Jamaica	49,803	278,425
Colombia	320,649	513,348
Venezuela	37,695	158,526
Surinam	42,645	142,790
Peru	151,358	396,141
Chile	123,234	205,258
Brazil	114,892	119,524
Sweden	15,451	94,047
Finland	30,289	279,984
United Kingdom	264,110	374,256
Ireland	81,400	366,739
The Netherlands	15,083	113,214
Belgium	20,239	139,314
France	41,189	177,591
West Germany	76,187	205,023
Switzerland	17,857	80,840
Spain	30,531	183,812
Italy	86,309	673,373
Greece	25,198	73,157
Iran	46,118	137,128
Israel	9,577	95,091
Kuwait	16,468	80,943
Saudi Arabia	466,441	256,331
India	145,126	64,691
Pakistan	13,920	64,832
Thailand	42,989	76,663
Singapore	153,448	408,972
Philippine Republic	229,895	551,008
Korean Republic	27,000	63,030
Taiwan	52,596	159,405
Japan	57,871	262,573
Australia	28,394	131,979
New Zealand	25,210	170,069
Nigeria	33,470	87,997
Republic of South Africa	35,719	242,818
Zambia	11,917	118,528
Other Countries	346,981	987,008
Total	4,749,049	10,791,265

*U. S. Bureau of the Census, 1975b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638117 Asbestos insulation, heat or sound		
2 Canada	--	729,888
Mexico	--	188,096
Dominican Republic	--	60,990
Venezuela	--	282,149
Surinam	--	282,149
Peru	--	81,658
Brazil	--	214,532
United Kingdom	--	130,610
The Netherlands	--	102,618
Belgium	--	253,755
Iran	--	66,323
Pakistan	--	143,518
Singapore	--	364,906
Philippine Republic	--	74,620
Mainland China	--	916,153
Japan	--	98,572
Australia	--	99,706
New Zealand	--	248,444
Egypt	--	68,333
Ghana	--	65,383
Other Countries	--	812,154
Total	--	5,071,672
6638120 Asbestos textiles and yarns		
3 Canada	7,749,305	3,664,189
Mexico	1,249,110	747,770
Peru	122,520	220,267
Sweden	122,929	230,746
United Kingdom	85,929	207,598
Ireland	45,100	145,350
The Netherlands	487,222	127,799
West Germany	195,984	252,944
Italy	54,043	274,700
Japan	23,646	146,510
Australia	1,020,703	614,452
Other Countries	307,061	651,974
Total	11,463,552	7,284,299

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*U. S. Bureau of the Census, 1975b

Table 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638150 Asbestos protective clothing		
Mexico	--	76,580
Greece	--	200,311
Saudi Arabia	--	68,643
Other Countries	--	463,975
Total	--	809,509
6638160 Asbestos manufactures, other than friction materials, NEC		
Canada	--	2,230,745
Mexico	--	246,573
Panama	--	74,099
Jamaica	--	70,179
Venezuela	--	749,761
Peru	--	305,139
Chile	--	182,659
Brazil	--	83,043
Sweden	--	1,145,722
United Kingdom	--	2,528,018
The Netherlands	--	702,650
West Germany	--	866,848
Switzerland	--	124,542
Poland	--	81,315
Lebanon	--	83,372
Iran	--	66,238
Saudi Arabia	--	185,369
Korean Republic	--	110,313
Japan	--	439,217
Australia	--	92,913
New Zealand	--	200,613
Republic of South Africa	--	325,572
Other Countries	--	845,089
Total	--	11,739,989

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*U. S. Bureau of the Census, 1975b

Tabla 4.4. U. S. Exports--By Country--of Asbestos Manufactured Products in 1975* (Cont'd)

	Net Quantity (Pounds)	Value (Dollars)
6638202 Asbestos clutch facings for automotive use, including linings		
Canada		506,277
Chile		63,447
United Kingdom		195,978
West Germany		226,888
Other Countries		281,518
Total		1,274,108
6638206 Asbestos clutch facings, NEC, including linings		
Canada		160,905
Other Countries		163,144
Total		324,049
6638215 Asbestos brake linings for automotive use		
1 Canada	5,726,553	4,681,018
Guatemala	55,287	95,364
Ecuador	76,894	114,637
Chile	26,188	63,495
Belgium	83,388	133,965
Greece	426,808	177,068
Lebanon	146,100	165,735
Iran	164,803	156,894
Singapore	133,140	82,093
Indonesia	118,415	73,897
Other Countries	700,518	869,554
Total	7,658,094	6,613,702
6638225 Asbestos brake linings, NEC		
6 Canada	1,487,000	1,594,737
Mexico	274,572	173,896
Brazil	20,913	148,892
The Netherlands	26,700	271,849
Japan	15,909	64,690
Australia	48,975	136,347
Other Countries	180,307	369,465
Total	2,054,376	2,759,876

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* U. S. Bureau of the Census, 1975b

4.3 Imports

Table 4.5 below lists the American imports of asbestos (unmanufactured) from 1965 to 1975.

Table 4.5. U.S. Imports of Asbestos (Unmanufactured) for 1965 - 1976 (Clifton, 1977; U.S. Bureau of the Census, 1975 a)

Year	Asbestos Import in Thousands of Short Tons
1976	658
1975	539
1974	766
1973	792
1972	736
1971	682
1970	649
1969	695
1968	737
1967	646
1966	720
1965	719

In 1975, 539,000 short tons of asbestos were imported into the U.S., as compared to 766,000 short tons in 1974. The decrease from 1974 to 1975 was due to a shortage of asbestos in the Canadian supply caused by: 1) a destructive fire at Thetford Mines, Quebec, 2) a landslide at Johns-Manville's Jeffrey Mine, Quebec, and 3) the 7-month-long strike of Quebec asbestos workers (Asbestos Magazine, December, 1975). During 1976, 658,000 short tons of asbestos were imported, a rate which is approximately midway between the 1974 and 1975 figures.

Tables 4.6a and 4.6b list U.S. imports, by country, of unmanufactured asbestos in 1975 and the first-half of 1976, respectively. Table 4.7 gives similar data for 1973 - 1974. Table 4.8 lists U.S. imports, by country, of manufactured asbestos products in 1975. A historical breakdown for asbestos imports of chrysotile, crocidolite, and amosite is included in Table 4.9, Asbestos Supply-Demand Relationships.

During the entire history of the asbestos industry in the U.S., domestic sources have been able to meet only a small percentage of U.S. requirements. Canada furnished 96% of all the asbestos tonnage imported by the U.S. (1969 - 1973), but only a small portion (3%) was spinning grade fibers. The comparatively small tonnages imported from Africa are more important than would appear on a tonnage basis because they consist largely of special kinds and qualities unobtainable elsewhere (Clifton, 1975).

4.4 Supply-Demand-Use

Table 4.9 gives the asbestos supply-demand relationships for 1967 - 1976. The U.S. supply is a combination of imports, domestic mine production, industry stockpiles, and governmental stockpile releases. The U.S. supply is distributed among industry and governmental stockpile acquisitions, exports, and industry demand. The relative importance of each is apparent from Table 4.9. The asbestos distribution by end use, grade, and type for 1976 is shown in Table 4.10. The major buyers of asbestos and asbestos ore are listed in Table 4.11.

4.5 Asbestos Fiber Prices

Asbestos prices are characterized by an erratic price history. Prices for Canadian asbestos increased about 8% in 1973, 39% in 1974, and 23% in 1975.

Table 4.6a. U.S. Imports--by Country--of Unmanufactured Asbestos in 1975

	Net Quantity Short Tons	Value (dollars)**		
		Customs	F.a.s.	C.i.f.
2764010	Asbestos, Amosite			
Rep SAF	3,894	1,539,951	1,542,143	1,872,035
Total	3,894	1,539,951	1,542,143	1,872,035
2764020	Asbestos, Crocidolite, Blue			
Mozambq	118	16,090	16,090	29,033
Rep SAF	11,570	4,942,886	4,942,181	6,100,733
Total	11,688	4,958,976	4,958,271	6,129,766
2764030	Asbestos, Chrysotile Crudes			
Canada	71	9,045	9,654	9,654
U King	277	82,982	82,982	121,299
Belgium	22	2,670	2,670	4,408
USSR	4,525	920,772	920,772	1,617,748
Rep SAF	940	663,658	663,658	760,556
Swazlnd	2,756	952,544	952,544	1,291,259
Rhodesia	1,633	1,521,421	1,520,611	1,753,361
Total	10,244	4,153,092	4,152,891	5,558,285
2764040	Asbestos, Chrysotile, Except Crudes and Spinning Fibers			
Canada	7,637	5,772,397	5,879,920	5,893,666
Rep SAF	115	99,572	99,572	109,296
Rhodesia	382	368,845	368,845	414,831
Total	8,134	6,240,814	6,348,337	6,417,793
2764050	Asbestos, Chrysotile, Except Crudes and Spinning Fibers			
Canada	490,615	91,014,320	96,411,691	96,526,478
Mexico	73	14,876	14,876	14,876
U King	58	11,396	11,890	11,890
USSR	86	38,640	39,805	40,214
Italy	44	12,540	12,540	16,461
Gaza St	152	25,914	25,914	25,914
Rep SAF	220	68,025	68,276	95,123
Rhodesia	32	22,871	22,871	27,614
Total	491,280	91,208,582	96,607,863	96,758,570
2764060	Asbestos, Unmanufactured, Crudes, Fibers, Stucco, Etc., NES			
Canada	5,222	776,931	858,340	859,639
Finland	329	32,841	32,298	51,915
Belgium	48	4,599	4,599	7,426
USSR	5,768	1,321,982	1,321,982	1,822,332
Italy	153	23,868	23,868	38,805
Rep SAF	1,237	391,099	424,487	533,022
Rhodesia	576	357,486	357,486	473,331
Total	13,333	2,908,806	3,023,060	3,786,470

*Source: U.S. Bureau of the Census, 1975a

**Customs Value: Value of imports appraised by U.S. Customs Service.
F.a.s. Value: Transaction value of imports at foreign port of exportation.
C.i.f. Value: Value of imports at the first port of entry in U.S.

Table 4.6b. U.S. Imports--by Country--of Unmanufactured Asbestos, January to June, 1976*

	Net Quantity Short Tons	Value (dollars)		
		Customs	F.a.s.	C.i.f.
2764010	Asbestos, Amosite			
Rep SAF	1,151	503,663	509,697	642,607
Oth Cty	20	469	669	669
Total	1,171	504,132	510,366	643,276
2764020	Asbestos, Crocidolite, Blue			
Rep SAF	4,712	2,315,466	2,388,971	2,606,013
Total	4,712	2,315,466	2,388,971	2,606,013
2764030	Asbestos, Chrysotile Crudes			
Canada	289	125,175	129,108	129,108
Mexico	234	125,486	126,948	126,948
U King	119	55,992	55,992	64,090
Rep SAF	351	193,918	193,913	220,191
Rhodesia	1,095	1,115,230	1,115,230	1,200,965
Total	2,088	1,615,801	1,621,196	1,741,302
2764040	Asbestos, Chrysotile Spinning Fibers			
Canada	2,394	2,053,568	2,110,240	2,111,611
Total	2,394	2,053,568	2,110,240	2,111,611
2764050	Asbestos, Chrysotile, Except Crudes and Spinning Fibers			
Canada	298,988	60,006,713	63,427,681	63,598,407
Fr Germ	1,086	202,826	202,826	257,094
Rep SAF	396	217,440	219,660	235,599
Oth Cty	17	3,919	3,919	3,919
Total	300,487	60,430,898	63,854,086	64,095,019
2764060	Asbestos, Unmanufactured, Crudes, Fibers, Stucco, Etc., NES			
Canada	8,759	1,450,342	1,571,118	1,572,326
Fr Germ	823	179,840	179,840	320,577
USSR	6,700	1,292,721	1,293,001	2,079,238
Rep SAF	1,953	898,889	920,675	981,292
Oth Cty	54	21,969	22,029	22,368
Total	18,289	3,843,761	3,986,663	4,975,801

*Source: U.S. Bureau of the Census, 1976a

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Table 4.7. U.S. Imports for Consumption of Asbestos (Unmanufactured) by Class and Country (Clifton, 1974)

Year and country	Crude (including blue fiber)		Textile fiber		All other		Total	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
1973								
Canada	1,991	$397	15,665	$6,020	746,988	$86,449	764,644	$92,866
Finland	--	--	--	--	1,027	93	1,027	93
Germany, West	79	21	--	--	--	--	79	21
Guyana	--	--	--	--	303	8	303	8
Italy	--	--	--	--	8	3	8	3
Malagasy, Republic	--	--	--	--	3	1	3	1
Mexico	--	--	--	--	43	7	43	7
Mozambique	51	27	--	--	5	1	56	28
Panama	--	--	--	--	12	11	12	11
Portugal	--	--	--	--	1	(1)	1	(1)
Rhodesia, Southern	845	423	--	--	--	--	845	423
South Africa, Republic of	21,629	4,510	8	1	3,427	733	25,064	5,244
Swaziland	200	122	130	73	--	--	330	195
Yemen	--	--	--	--	50	11	50	11
Yugoslavia	--	--	--		8	3	8	3
Total	24,795	5,500	15,803	6,094	751,875	87,320	792,473	98,914
1974								
Brazil	--	--		--	20	2	20	2
Canada	115	13	26,768	10,416	712,228	106,085	739,111	116,514
Finland	--	--	-		557	74	557	74
Germany, West	99	35	--		1	1	100	36
Italy	--	--	1	4	--	--	1	4
Mexico	--	--	--	--	55	11	55	11
Portugal	--	--	--	--	4	2	4	2
Rhodesia	1,717	1,010	4	2	--	--	1,721	1,012
South Africa, Republic of	20,307	5,157	66	16	3,291	510	23,664	5,683
Swaziland	480	361	-		--	--	480	361
U.S.S.R	--	--	-		451	123	451	123
Total	22,718	6,576	26,839	10,438	716,607	106,808	766,164	123,822

[1] Less than ½ unit.

Table 4.8. U.S. Imports--by Country--of Manufactured Asbestos Products in 1975*

	Net Quantity Pounds	Value (dollars)		
		Customs	F.a.s.	C.i.f.
6618340	Asbestos & Hydraulic Cement Articles NES			
Canada	12,176,880	1,700,400	1,773,749	1,773,779
Mexico	282,803	73,555	73,564	73,564
Guatmal	532,566	43,941	43,941	60,097
Colomb	15,259,038	1,494,207	1,494,215	1,760,082
U King	9,246	5,350	5,368	5,995
Belgium	7,395,456	1,858,386	1,858,022	2,168,971
W Germ	4,149,943	377,706	377,705	564,244
Japan	145,941	30,725	30,725	36,848
Austral	246,333	56,234	59,555	70,473
Total	40,198,206	5,640,504	5,716,844	6,514,053
6638000	Asbestos Articles, NES, and Asbestos Yarn, Sliver, Rope, Etc., With or Without Wire			
Canada		3,988,524	4,010,223	4,019,687
Mexico		2,624,027	2,478,821	2,617,067
Venez		40,381	40,381	42,674
Brazil		841,938	831,938	872,701
Sweden		128,742	128,721	142,887
Norway		6,369	6,369	7,749
Finland		8,499	8,499	9,149
Denmark		12,780	12,189	12,594
U King		4,373,180	4,380,595	4,794,464
Nethlds		11,139	11,139	11,578
Belgium		32,774	32,795	35,867
France		137,475	137,897	147,444
W Germ		1,282,955	1,278,071	1,346,141
Switzld		6,187	6,187	7,168
Spain		495,545	495,545	531,694
Italy		156,022	156,022	172,358
Yugoslv		17,664	17,664	19,251
Greece		1,140	1,140	1,226
India		5,261	5,261	5,919
Phil R		1,000	1,000	1,555
Kor Rep		257,256	244,970	255,633
China T		1,094,659	1,075,207	1,154,996
Japan		1,149,464	1,135,904	1,228,451
Rep SAF		119,527	119,527	120,127
Total		16,792,508	16,616,065	17,558,380

*Source: U.S. Bureau of the Census, 1975a

Table 4.9. Asbestos Supply-demand Relationships, 1967-76
(Thousand short tons) (Clifton, 1977)

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
World mine production:										
United States	123	121	126	125	131	132	150	113	99	115
Rest of world	3,084	3,170	4,042	3,672	3,816	4,050	4,448	4,423	4,410	*4,885
Total	3,207	3,291	4,168	3,797	3,947	4,182	4,598	4,536	4,509	*5,000
Components of U.S. supply:										
Domestic mines	123	121	126	125	131	132	150	113	99	123
Shipments of Government stockpile excesses	1	1	5	11	8	16	7	29	7	2
Imports, chrysotile	618	703	669	626	660	724	771	747	523	646
Imports, crocidolite	15	14	11	9	7	5	13	11	12	10
Imports, amosite	13	20	15	14	15	7	8	8	4	2
Industry stocks, Jan. 1	19	17	18	23	21	30	96	103	103	104
Total U.S. supply	789	876	844	808	842	914	1,045	1,011	748	887
Distribution of U.S. supply:										
Government acquisition	1	....	....	7	....	....	....	....	....	....
Industry stock, Dec. 31	20	18	24	20	29	46	103	103	104	115
Exports	47	41	36	47	54	59	66	62	36	47
Industry demand	721	817	784	734	759	809	876	846	608	725
U.S. demand pattern:										
Flooring products	179	204	196	184	191	202	218	153	136	113
Asbestos cement pipe	134	155	149	139	144	154	166	222	153	140
Roofing products	71	82	79	73	76	81	87	76	46	253
Friction products	65	74	71	66	68	73	79	80	66	64
Asbestos cement sheet	51	57	55	51	53	57	64	95	44	23
Packing and gaskets	22	25	24	22	23	24	26	29	17	20
Insulation	22	25	24	22	23	24	26	14	6	9
Paper products	14	16	16	15	15	16	18	63	66	31
Textiles	14	16	16	15	15	16	18	20	6	7
Other	145	163	154	147	151	162	174	94	68	65
Total U.S. demand	721	817	784	734	759	809	876	846	608	725

*Estimate.

Table 4.10. Asbestos Distribution by End Use, Grade, and Type, 1976
(Short tons) (Clifton, 1977)

	Chrysotile								Crocid-olite	Amosite	Antho-phyllite	Total asbestos
	Gr. 1 and 2	Gr. 3	Gr. 4	Gr. 5	Gr. 6	Gr. 7	Gr. 8	Total chryso-tile				
Asbestos cement pipe	....	600	86,300	26,600	3,100	200	....	116,800	20,300	2,900	....	140,000
Asbestos cement sheet	....	1,000	2,100	3,600	9,800	5,900	....	22,400	....	200	100	22,700
Flooring products	1,500	1,100	....	6,300	600	104,000	....	113,500	....	....	....	113,500
Roofing products	....	....		400	1,900	251,300	....	253,600	....	....	....	253,600
Packing and gaskets	....	1,800	5,900	8,300	700	3,300	....	20,000	100	....	....	20,100
Insulation, thermal	....	....	800	200	1,900	3,600	....	6,500	....	100	....	6,600
Insulation, electrical	....	100	....	100	200	1,900	....	2,300	....	....	....	2,300
Friction products	....	2,800	1,500	21,100	6,800	31,000	200	63,400	....	100	300	63,800
Coatings and compounds	....	....	300	300	100	19,200	....	19,900	....	....	....	19,900
Plastics	....	200	2,800	100	1,200	15,400	....	19,700	700	....	1,100	21,500
Textiles	200	6,900	300	....	....	....	....	7,400	....	....	....	7,400
Paper	....	100	1,600	3,300	22,200	3,500	....	30,700	300	....	....	31,000
Other	....	300	800	2,500	4,400	14,700	....	22,700	....	1,200	....	23,900
Total	1,700	14,900	102,400	72,800	52,900	454,000	200	698,900	21,400	4,500	1,500	726,300

Table 4.11. Buyers of Asbestos and Asbestos Ore (Compiled from data furnished by U.S. Bureau of Mines, Washington, D.C.)*

Armstrong Cork Co., West Liberty & Charlotte St., Lancaster, Pa. 17604
Asbestos Textile Co., 165 West Wacker Dr., Chicago, Ill. 60601
Carlisle Corp., 621 North College, Carlisle, Pa. 17013
Celotex Corporation, L'Anse, Mich. 49946
Certain-Teed Products Corp., 120 East Lancaster Ave., Ardmore, Pa. 19003
Firestone Tire & Rubber Co., 1200 Firestone Pky., Akron, Ohio 44317
Flintkote Co., The, Inc., 400 Westchester Ave., White Plains, New York 10604
Foseco, Inc., 20200 Sheldon Rd., Brook Park, Ohio 44403
GAF Corp., 140 West 51st St., New York, N.Y. 10020
Garlock Inc., 250 Main St., Palmyra, N.Y. 14522
Gatke Corp., Box 308 East Winona, Warsaw, Ind. 46580
Hooker Chemical Corp., Kenton, Ohio 43326
International Vermiculite Co., Girard, Ill. 62640
Johns-Manville Corp., Greenwood Plaza, Denver, Colo. 80217
Mead Corp., 118 West First St., Dayton, Ohio 45402
Minnesota Mining & Mfg. Co., 3M Center, St. Paul, Minn. 55101
National Gypsum Co., Inc., 325 Delaware Ave., Buffalo, N.Y. 14202
Owens-Corning Fiberglass Co., Berlin, N.J. 08009
Pittsburgh Corning Corp., No. 1 Gateway Center, Pittsburgh, Pa. 15207
H.K. Porter Co., Inc., 601 Grant St., Pittsburgh, Pa. 15219
Raybestos Manhattan, Inc., Bridgeport, Conn. 06601
Rogers Corp., Rogers, Conn. 06263
Standco Brake Lining Co., 2701 Clinton Dr., P.O. Box 93, Houston, Tex. 77020
U.S. Gypsum Co., 101 South Wacker, Chicago, Ill. 60606
U.S. Plywood Corp., South River, N.J. 08882

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* List not considered complete.

Table 4.12 lists the average annual asbestos price from 1956 to 1976 and compares it to a figure based on constant 1975 dollars. Table 4.13 lists recent prices for various grades and origins of asbestos. The remarkable disparity of grade prices is evident from Quebec chrysotile fiber prices. Grade No. 7 (shorts) was priced at $89 per ton, while Grade No. 1 (crudes) cost $3496 per ton.

4.6 Future Outlook

Projections for future use of asbestos are reported by Clifton (1977). The information and projections contained in this subsection come directly from Clifton (1977).

The domestic demand for asbestos is expected to increase at a slow rate; the low rate of annual growth is expected to be 1.0%, while the high rate is expected to be 3.8%. The U.S. demand for asbestos in the year 2000 is projected to be about 1.3 times that the 20 year trend point for 1975. Projection trends for the U.S. demand are illustrated in Figure 4.2. The forecast for U.S. demand of asbestos by end use is given in Table 4.14.

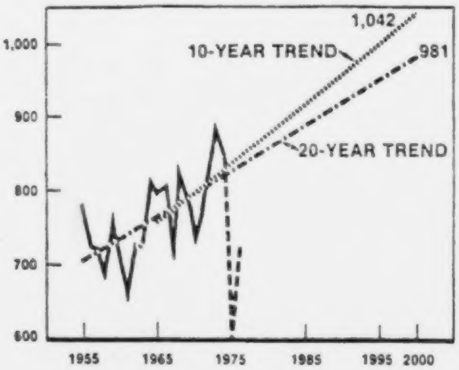

Figure 4.2. U.S. Asbestos Demand and Projected Trends to 2000 (thousand short tons) (Clifton, 1977)

Table 4.12. Time-Price Relationship for Asbestos (Clifton, 1977)

	Average Annual Price, Dollars Per Short Ton	
Year	Actual Price	Constant 1975 Dollars
1956	89.78	181.63
1957	88.09	172.38
1958	90.50	174.34
1959	91.17	171.83
1960	94.62	175.35
1961	95.60	175.61
1962	94.85	171.09
1963	92.44	164.31
1964	98.70	172.73
1965	97.92	167.67
1966	100.63	166.82
1967	101.91	164.11
1968	98.93	152.46
1969	110.03	161.46
1970	115.64	161.06
1971	117.54	155.76
1972	116.63	148.42
1973	122.22	147.01
1974	122.27	133.65
1975	144.14	144.14
1976	206.31	197.56

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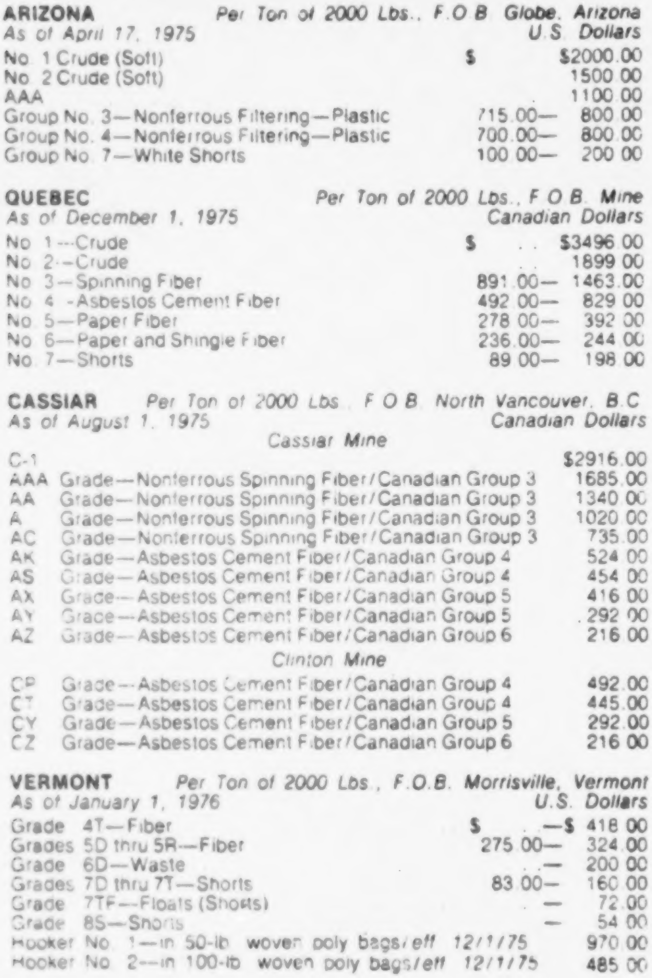
Table 4.13. 1975 Prices of Various Asbestoses (Asbestos Magazine, December, 1975)



ARIZONA	*Per Ton of 2000 Lbs., F.O.B. Globe, Arizona*	
As of April 17, 1975		*U.S. Dollars*
No. 1 Crude (Soft)	$	$2000.00
No. 2 Crude (Soft)		1500.00
AAA		1100.00
Group No. 3—Nonferrous Filtering—Plastic	715.00—	800.00
Group No. 4—Nonferrous Filtering—Plastic	700.00—	800.00
Group No. 7—White Shorts	100.00—	200.00
QUEBEC	*Per Ton of 2000 Lbs., F.O.B. Mine*	
As of December 1, 1975		*Canadian Dollars*
No. 1—Crude	$ . .	$3496.00
No. 2—Crude	. .	1899.00
No. 3—Spinning Fiber	891.00—	1463.00
No. 4—Asbestos Cement Fiber	492.00—	829.00
No. 5—Paper Fiber	278.00—	392.00
No. 6—Paper and Shingle Fiber	236.00—	244.00
No. 7—Shorts	89.00—	198.00
CASSIAR	*Per Ton of 2000 Lbs., F.O.B. North Vancouver, B.C.*	
As of August 1, 1975		*Canadian Dollars*
	Cassiar Mine	
C-1		$2916.00
AAA Grade—Nonferrous Spinning Fiber/Canadian Group 3		1685.00
AA Grade—Nonferrous Spinning Fiber/Canadian Group 3		1340.00
A Grade—Nonferrous Spinning Fiber/Canadian Group 3		1020.00
AC Grade—Nonferrous Spinning Fiber/Canadian Group 3		735.00
AK Grade—Asbestos Cement Fiber/Canadian Group 4		524.00
AS Grade—Asbestos Cement Fiber/Canadian Group 4		454.00
AX Grade—Asbestos Cement Fiber/Canadian Group 5		416.00
AY Grade—Asbestos Cement Fiber/Canadian Group 5		. 292.00
AZ Grade—Asbestos Cement Fiber/Canadian Group 6		216.00
	Clinton Mine	
CP Grade—Asbestos Cement Fiber/Canadian Group 4		492.00
CT Grade—Asbestos Cement Fiber/Canadian Group 4		445.00
CY Grade—Asbestos Cement Fiber/Canadian Group 5		292.00
CZ Grade—Asbestos Cement Fiber/Canadian Group 6		216.00
VERMONT	*Per Ton of 2000 Lbs., F.O.B. Morrisville, Vermont*	
As of January 1, 1976		*U.S. Dollars*
Grade 4T—Fiber	$ . . —$	418.00
Grades 5D thru 5R—Fiber	275.00—	324.00
Grade 6D—Waste	. . —	200.00
Grades 7D thru 7T—Shorts	83.00—	160.00
Grade 7TF—Floats (Shorts)	. —	72.00
Grade 8S—Shorts	—	54.00
Hooker No. 1—in 50-lb. woven poly bags/eff 12/1/75		970.00
Hooker No. 2—in 100-lb. woven poly bags/eff 12/1/75		485.00

Table 4.14. Projections and Forecasts for U.S. Asbestos Demand By End Use, 1975 and 2000 (Thousand Short Tons) (Clifton, 1977)

End Use	1975	2000			
		Contingency Forecasts for United States			
		Forecast Base	Forecast Range		Probable
			Low	High	
Asbestos cement pipe	153	244	270	527	274
Asbestos cement sheet	44	95	115	224	116
Flooring products	136	323	187	364	189
Roofing products	46	128	92	180	93
Packing and gaskets	17	38	35	68	35
Friction products	66	124	97	189	98
Insulation	6	39	17	33	17
Paper	66	28	76	149	77
Textiles	6	29	24	47	24
Other	68	256	113	219	115
Total	608	---	1,026	2,000	1,038

[1] The forecast base for friction products is derived from statistical analysis on data for 1960-75. All other 2000 forecast base figures are based on data for 1960-73.

5.0 MINING AND MILLING

5.1 U.S. Mines and Mills

Although mineral deposits which sometimes contain asbestos are located throughout the United States (Figure 5.1), asbestos is mined in only a few states. The map in Figure 5.2 designates the location of mines which are operating or which have been closed recently. In order of decreasing annual production, the mining states are California, Vermont, Arizona, and North Carolina. Table 5.1 lists the American mines which are operating or have recently closed, along with the associated mills. All of the mines produce chrysotile asbestos with the exception of the Powhattan mine in North Carolina which produced anthophyllite asbestos.

The largest mines are the Vermont Asbestos Group mine (formerly owned by GAF Corp.) in Vermont and the Calaveras Asbestos Ltd. mine (formerly controlled by H.K. Porter Co.) in Copperopolis, California (Asbestos Magazine, December, 1975). The inactive Coalinga Asbestos Co. mine (Johns-Manville) was the second largest mine in California and the third largest nationally. Environmental regulations are cited as the prime reasons for the closing of the Johns-Manville mine (Clifton, 1976; Harwood and Blasznak, 1974; Asbestos Magazine, December, 1974, 1975). The Powhattan mine in North Carolina was reported as inactive since 1973 (Harwood and Blasznak, 1974).

Potential mining has been discussed for Alamore, Texas (tremolite asbestos), Sonora, California, and the Yukon region of Alaska (Asbestos Magazine, December, 1972, 1974).

It should be noted that actual mining production data for each mine cannot be accurately reported for proprietary reasons. Since California had,

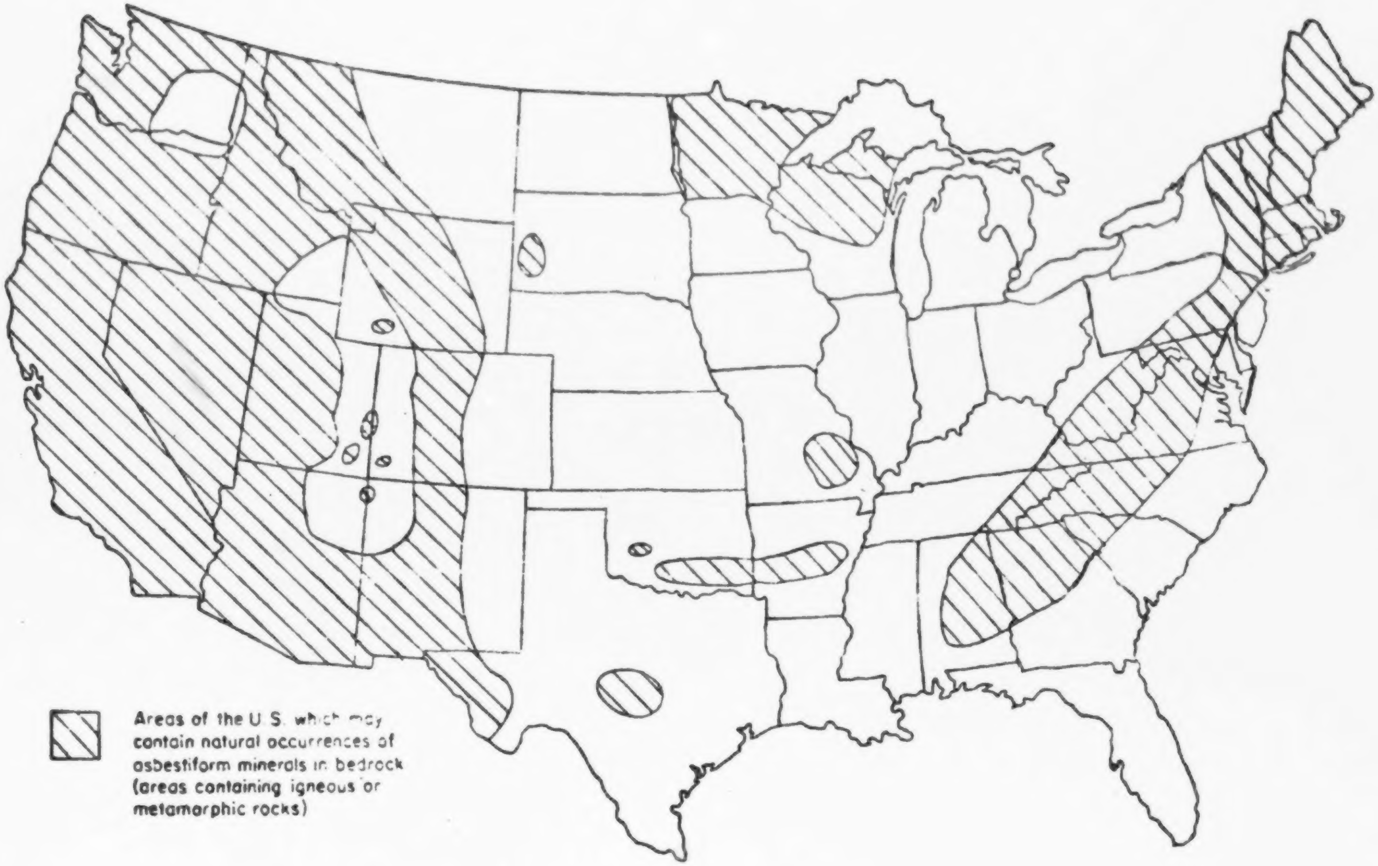

Areas of the U.S. which may contain natural occurrences of asbestiform minerals in bedrock (areas containing igneous or metamorphic rocks)

Figure 5.1. Possible Areas of Asbestiform Minerals (Harwood and Blasznak, 1974)

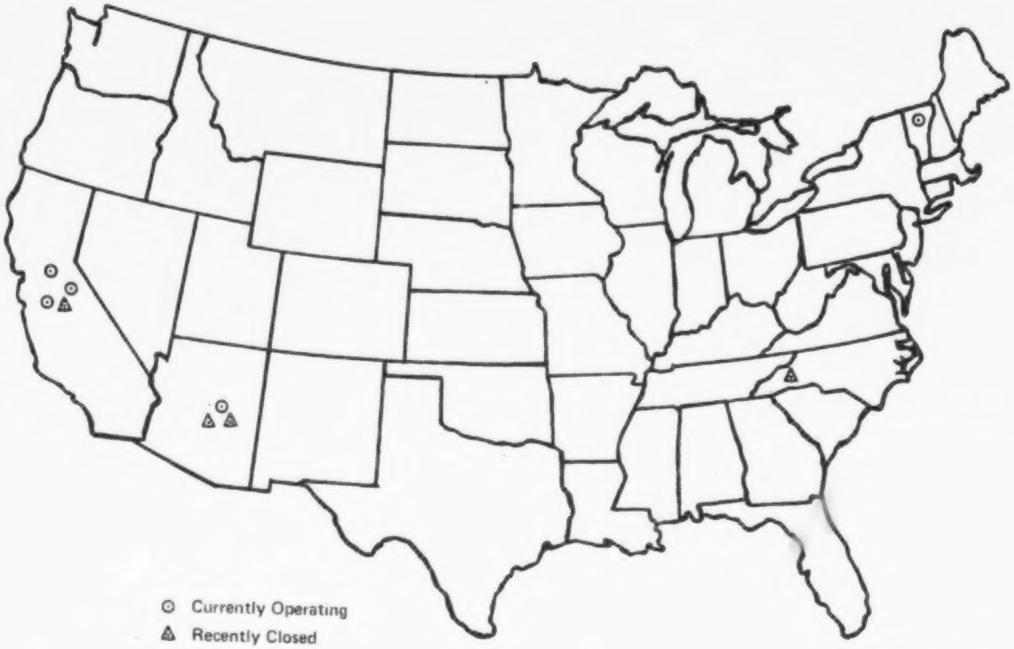

A24755-U
⊙ Currently Operating
▲ Recently Closed

Figure 5.2. Asbestos Mines in the United States

Table 5.1. American Asbestos Mines and Mills (Harwood and Blasznak, 1974; Clifton, 1974, 1975; Asbestos Magazine, December, 1972 - 1975) Note: All mines are open pit except those in Arizona, which are underground.

	Operating Company	Mine Location	Employees*	Mill Location	Employees*	Estimated Production (Short Tons)	Comments
1.	Atlas Asbestos Co.	Fresno County, Calif.	20	Coalinga, Calif.	50	25,000/yr.	Used in vinyl-floor tile
2.	Calaveras Asbestos Ltd.	Calaveras County, Calif.	36	Copperopolis, Calif.	135	220/day	Used in asbestos-cement pipes and sheets
3.	Union Carbide	San Benito County, Calif.	36	King City, Calif.	50	110/day	Used in reinforcing thermoplastics (Calidria); Japan is a major consumer
4.	Coalinga Asbestos Co., div. of Johns-Manville	Fresno County, Calif.	20	Coalinga, Calif.	50	110/day	Closed in June, 1974
5.	Vermont Asbestos Group	Hyde Park, Vt.	58	Hyde Park, Vt.	143	220/day	Used in heat-resistant materials, mostly by GAF; purchased in 1975 from GAF
6.	Jacquays Mining Corp.	Gila County, Ariz.	8	Globe, Ariz.	5	3,000/yr.	Used for electrical and filter media; most is exported to Japan
7.	Asbestos Mfg. Co.	Gila County, Ariz.	--	Globe, Ariz.	---	Closed	Closed
8.	Metate Asbestos Co.	Gila County, Ariz.	--	Globe, Ariz.	---	Closed	Closed
9.	Powhattan Mining Corp.	Burnside, N.C.	4	Baltimore, Md.	8	700/yr.**	---

* 1973 figures (Harwood and Blasznak, 1974)
** Mill capacity figure

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until recently, several operating mines, the Bureau of Mines has reported annual production for the state. But as a result of recent mine closings, the annual California production report might be terminated (Clifton, 1976). Table 5.1 contains estimates of Harwood and Blasznak (1974) for several individual daily mine productions and the estimate of Asbestos Magazine for annual production of two mines. Based upon the combined data of Harwood and Blasznak, Clifton, and Asbestos Magazine, we estimate that at the present time about 55- 65% of the asbestos mined in the U.S. is mined in California, 35-45% comes from Vermont, and less than 5% is mined in Arizona and North Carolina. Until recent mine closings and sales altered the California production, California had accounted for nearly 70% of the domestic fiber.

The lower limit for economical asbestos production is estimated at 4% asbestos containing ore (Berger and Oesper, 1963). Clifton (1975) evaluated the effect of continuous mine operations on the percent fiber recovery by a linear regression analysis of Quebec mine data (see Figure 5.3). He forecasts that as the age of a mine increases, the percent fiber recovery decreases. This will result in an increasing fiber production cost until mining is no longer profitable. By reason of analogy, the Quebec data should be generally true for U.S. mines, especially the Vermont mine, which is an outcrop of the Quebec deposits. Based on the above data, the Vermont mine could be close to being mined out.

5.1.1 Ore Characteristics

The chrysotile asbestos content of ore varies between deposit locations. The lowest concentration is deposited in the Vermont ore which consists of less than 4% asbestos by weight, and the highest concentration is

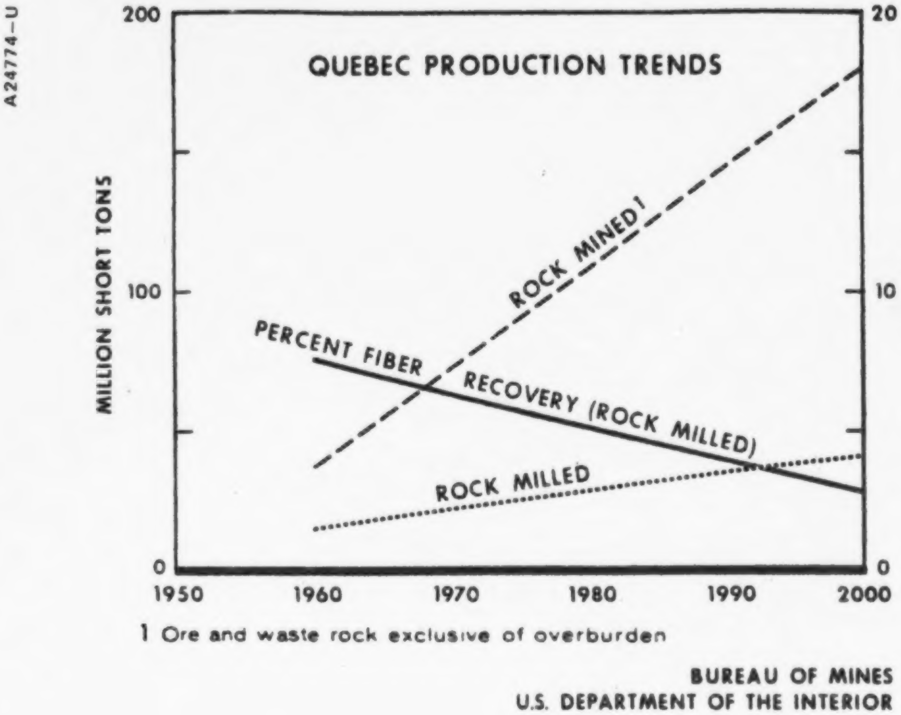

Figure 5.3. Quebec Production Trends, From Analysis of 1951 - 1970 Data (Clifton, 1975)

deposited in the Coalinga, California, district which is approximately 60% by weight asbestos.

The Vermont ore deposit is an outcrop of the large Quebec deposits in Canada. While the Vermont deposit contains some spinning grade fibers (Harwood and Blasznak, 1974), most fiber is shorter grade and is consumed in the manufacture of heat resistant products (Asbestos Magazine, December, 1973).

The Calaveras Asbestos Ltd. mine in Copperopolis, California, produces the normal long fibered form of chrysotile asbestos which is primarily used in asbestos-cement products (Harwood and Blasznak, 1974; Asbestos Magazine, December, 1975). Three mines, the Coalinga (Johns-Manville), Atlas, and Union Carbide, are in close proximity to each other near Coalinga, California. They work an ore body which is 10 miles long and 0.25 miles wide. The ore from these mines is atypical of asbestos. Instead of a fibrous vein structure, the asbestos is in a platy, slippery form known locally as desert leather (Harwood and Blasznak, 1974). The fibers from this tract are short and therefore are used in floor tile and reinforced thermoplastics (Asbestos Magazine, December, 1971, 1975). Arizona produces an exceptionally high quality, low iron content asbestos, most of which is used for electrical insulation and for filtering media (Asbestos Magazine, December 1975). Most of the Jacquay Mine production is exported to Japan (Harwood and Blasznak, 1974).

6.0 FRICTION MATERIALS

Friction materials are used in practically all industries as a key component in clutches for transmitting torque, brakes for slowing down or stopping motion, or as torque limiters. Although friction applications to automobile brakes and clutches are the most important commercially, asbestos-friction applications are not limited to brakes and clutches in automobiles, trucks, busses, construction equipment, and railroad cars. Rather, these applications are found wherever motion must be controlled. The following examples show the diversification of friction material usage: farm tractors, presses, hoists, tensioning devices in production of wire and plastic rope and cable, lift trucks, machine tools, shuttlecars, specialized mining equipment, chainsaws, drilling equipment, spinning and knitting equipment, x-ray machines, wheel brakes, tape recorders, typewriters, bicycle brakes, snowblowers, and washing machines (Daly et al., 1976). Asbestos is an important ingredient in these friction material products because it imparts strength, good friction properties, can withstand high temperatures, and is a good insulator.

6.1 Statistics

6.1.1 Use Quantity and Shipment Values

From Table 4.9 (p. 46), it can be seen that U.S. demand for asbestos in friction products has ranged from sixty-five to eighty thousand short tons annually from 1967 to 1976. This amounts to approximately 9% of the total U.S. asbestos demand (consumption).

The trend in the value of shipments of asbestos friction materials is shown in Table 6.1. During the five year period from 1967 to 1972, shipment

Table 6.1. Value of Shipments of Asbestos Friction Materials (U.S. Bureau of the Census, 1972 Census of Manufacturers)

SIC Product Code		Product	Total Product Shipments, including interplant transfers (millions dollars)		
			1972	1967	1963
32922	--	Asbestos Friction Materials - Total	209.5	144.4	177.7
		Brake Linings:			
32922	11	Woven, containing asbestos yarn, tape, or cloth	10.2	13.5	--
32922	15	Molded, including all non-woven types	113.1	95.6	--
32922	21	Disc Brake Pads	14.2	--	--
		Clutch Facing:			
32922	51	Woven, containing asbestos yarn, tape, or cloth	19.9	17.2	--
32922	55	Molded, including all non-woven types	48.5	16.1	--
32922	00	Asbestos Friction Materials, n.s.k.	3.6	2.0	--

values increased by 45%, as compared to a 23% increase for the four-year period from 1963 to 1967. Using an annual figure of 9% for shipment value increases, the total product shipments of asbestos friction materials would be approximately $271.3 million in 1975 and $295.7 million in 1976.

Table 6.1 also gives a breakdown for the major asbestos friction material products. In 1972, brake linings accounted for nearly 59% of shipment values while clutch facings accounted for slightly over 32% of the shipment values. If disc brake pads are included along with brake linings, then asbestos brake-materials account for 65.6% of the total value of asbestos-friction materials. Clearly then, "brakes" are by far the most important commercial product in the friction material category.

6.1.2 Industrial Firms

Table 6.2 lists the U.S. manufacturers of asbestos-bearing friction materials along with their respective sales of friction materials in 1975. The larger firms include not only the essentially captive producers, such as the Delco-Moraine and Inland Divisions of General Motors Corporation and the Cycleweld Division of Chrysler Corporation, but also the diversified industrial product manufacturers, such as Raybestos-Manhattan, Bendix, Abex, and H.K. Porter. In addition, the list includes many smaller, typically single-plant firms, which manufacture friction products for both the original equipment and replacement market.

The first eight firms listed on Table 6.2 account for nearly 75 to 85% of the total estimated sales of asbestos friction products in 1975. This ratio is consistent with the historical pattern for the industry, which indicates that in the 1954 to 1967 period, the eight largest firms accounted for between 86 and 91% of the industry's value of shipments (Margolin and Igwe, 1975; U.S. Bureau of the Census, 1972).

Table 6.2. U.S. Manufacturers of Asbestos-Bearing Friction Materials (Economic Information Systems, Inc., 1976; Margolin and Igwe, 1975; SRC Estimates)

Company	Plant Location	Estimated 1975 Sales of Friction Materials ($ million)
Raybestos-Manhattan, Inc.	Stratford, Conn. Mannheim, Pa. Crawfordsville, Ind. Fullerton, Calif.	110.0
Bendix Corporation	Troy, N.Y. Cleveland, Tenn.	72.5
Abex Corporation	Cleveland, Ohio Troy, Michigan American Brakeblok Division Winchester, Va.	60.1
General Motors Corp.	Delco-Moraine Div. Dayton, Ohio Inland Division Dayton, Ohio	30.0
H.K. Porter Co.	Huntington, Indiana Richmond, Ky.	26.0
Chrysler Corporation	Cycleweld Division Trenton, Michigan	---
Borg Warner Corporation	Spring Division Bellwood, Ill.	---
World Bestos Co.	New Castle, Ind.	18.8
National Friction Products Corp.	Logansport, Ind.	10.2
Gatke Corporation	Warsaw, Ind.	10.0
Carlisle Corporation	Ridgeway, Pa.	9.7
Maremont Corporation	Grizzly Products Division Paulding, Ohio	8.7

Table 6.2. U.S. Manufacturers of Asbestos-Bearing Friction Materials (Cont'd)

Company	Plant Location	Estimated 1975 Sales of Friction Materials ($ million)
Scandura, Inc.	Charlotte, N.C.	----
Mar Pro Corporation	Grizzly Brake Division Chicago, Ill.	----
Standco Industries	Houston, Texas	8.7
Forcee Mfg. Corporation	Tappahannock, Va.	----
Royal Ind. Brake Products, Inc.	Danville, Ky.	5.7
Auto Friction Corp.	Lawrence, Ma.	5.7
L.J. Miley Co.	Chicago, Ill.	5.5
Friction Products Co.	Medina, Oh.	4.0
United States Brake Lining Corp.	Miami, Fla.	2.9
Brassbestos Mfg. Corp.	Patterson, N.J.	1.7
Southern Friction Material Co.	Charlotte, N.C.	----
Reddaway Mfg. Co.	Newark, N.J.	1.7
Molded Ind. Friction Corp.	Prattville, Ala.	----
Auto Specialties Mfg. Co.	St. Joseph, Mich.	----
Lasco Brake Products Co.	Oakland, Calif.	<1
California Blok Co.	Gardena, Calif.	<1
MGM Brakes, Inc.	Cloverdale, Calif.	<1
Wheeling Brake Block Mfg. Co.	Wheeling, W.Va. Bridgeport, Ohio	<1

Table 6.2. U.S. Manufacturers of Asbestos-Bearing Friction Materials (Cont'd)

Company	Plant Location	Estimated 1975 Sales of Friction Materials ($ million)
Baldwin-Ehnet Hill, Inc.	Trenton, N.J.	<1
Thiokol Chemical Corp.	Trenton, N.J.	<1
F.T. Brake Lining Co.	Lawrence, Mass.	----
Hunt/Airheart Products, Inc.	Chatsworth, Cal.	----
Re-Bilt Auto Products Corp.	Brooklyn, N.Y.	----

One important discrepancy in figures should be explained. For 1972, the U.S. Bureau of the Census listed the total value of shipments of asbestos friction products as $209.5 million which was projected as $271.3 million for 1975 in Section 6.1.1. From Table 6.2, the estimated sales of asbestos friction materials in 1975 total nearly $370 million for the listed figures; the companies with no listed figures may total another $50 million. The difference from the value of shipments as reported by the Bureau of the Census and the estimates given in Table 6.2 are due to variations in definition and reporting coverage. Shipment value does not include freight charges and excise taxes which are included in the actual sale cost. Also, the Bureau of the Census figures are based upon surveys at 23 asbestos-friction material establishments. Table 6.2 contains 44 establishments. Although the Bureau of the Census survey probably includes most of the larger establishments, the ones which were not surveyed are not available.

6.1.3 Plants

Figure 6.1 shows the geographical dispersion of friction materials plants in the U.S. Not surprisingly, they tend to be concentrated in and around the major metropolitan centers of the Northeast and Midwest, with a few plants located in California to primarily cater to the needs of the automobile assembly plants in that part of the country.

As would be expected of a mature industry, most of the plants and equipments are old, usually over forty years of age, with the possible exception of some captive facilities belonging to the automobile manufacturers. Production processes have changed only marginally over the years, and labor rather than capital intensity appears to be the norm in most of the older plants (Margolis and Igoe, 1975).

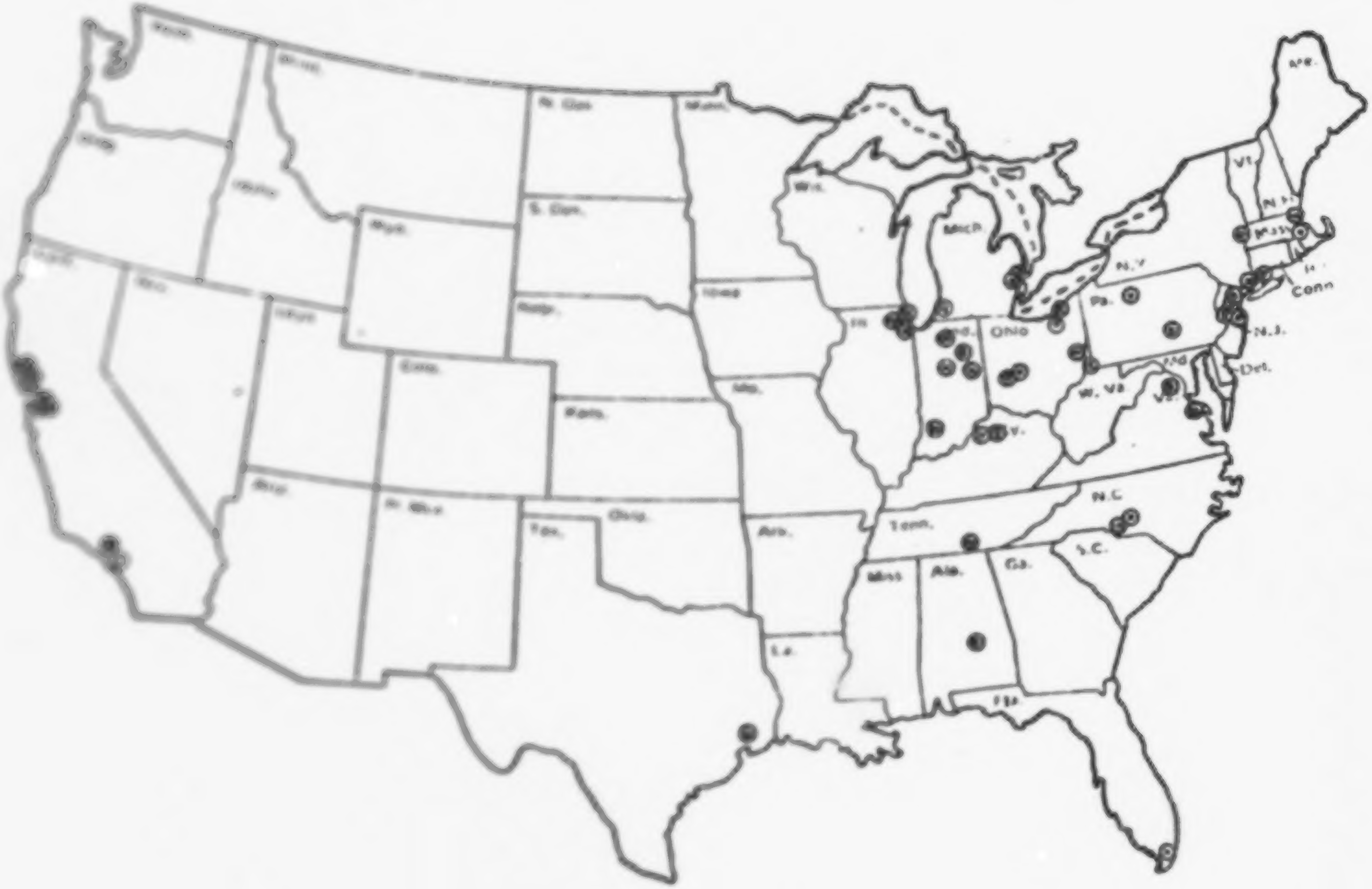
Me.
Vt.
N.H.
Mass.
Conn
N.J.
Del.
Md.
Va.
W. Va.
N.Y.
Pa.
Ohio
Ind.
Mich.
Ill.
Wis.
Ky.
Tenn.
N.C.
S.C.
Ga.
Ala.
Miss.
Fla.
La.
Ark.
Mo.
Iowa
Minn.
N. Dak.
S. Dak.
Nebr.
Kans.
Okla.
Tex.
N. Mex.
Colo.
Wyo.

Figure 6.1 Geographical Dispersion of U.S. Friction Materials Plants (Modified from Margolin and Igwe, 1975)

6.1.4 Future Projections for Asbestos Use (Clifton, 1975)

Asbestos demand for friction products was projected to the year 2000 at an annual growth rate of 1.50 percent. This figure was based on a formula derived from least-squares regression analysis of total asbestos demand modified by the estimated growth in the automobile industry and economic indicators, which showed the best correlation.

Asbestos is an important part of many types of friction materials for use in automobiles, trucks, and other transportation equipment. Modern industry could scarcely function without asbestos friction materials. In addition to using asbestos in brake linings, today's motor cars, equipped with automatic transmissions, get their drive from metal transmission disks, which are covered with a super-tough paper containing crocidolite asbestos. The average automobile with power shift contains from 8 to 12 of the paper lined disks. Although the quantity of asbestos in each transmission is small, the output of more than 8 million automatic transmissions annually requires disk paper production in hundreds of tons.

A new composition disk-brake-shoe unit containing asbestos, designed to meet the critical braking requirements for the new 150-mile-per-hour passenger train systems has been developed.

Based on an estimated forecast of the number of motor vehicles produced in the year 200 (approximately double 1973 production) and on the assumption that the use of asbestos per vehicle will remain at present levels, the forecast for asbestos demand in user-operated vehicles is projected to 116,000 tons. An increased number of public transportation vehicles and equipment using parts made of asbestos or maintaining the present quantity used per vehicle could result in demand as high as 144,000 tons.

6.2 Manufacturing Process Technology

Several different processes are used to manufacture asbestos brake linings and clutch facings. Manufacture can be accomplished by a molding process, in a dry or wet-mixed state, or by a woven process; these processes, which are described below, are taken from Gregg (1974). The raw materials used for forming asbestos-friction materials are discussed in Section 6.3.

6.2.1 Molded Products

6.2.1.1 Dry-Mix Process

The manufacturing steps typically used in dry-mix molded brake lining manufacture are shown in Figure 6.2. The bonding agents, metallic constituents, asbestos fibers, and additives are weighed and mixed in a two-stage mixer. The mix is then hand-tamped into a metal mold. The mold is placed in a preforming press which partially cures the molded asbestos sheet. The asbestos sheet is taken from the preforming press and put in a steam preheating mold to soften the resin in the molded sheet. The molded sheet is formed to the proper arc by a steam-heated arc former, which resets the resin. The arc-formed sheets are then cut to the proper size. The lining is then baked in compression molds to retain the arc shape and convert the resin to a thermoset or permanent condition. The lining is then finished and, after inspection, is packaged. The finishing steps include sanding and grinding of both sides to correct the thickness, edge grinding, and drilling of holes for rivets. Following drilling, the lining is vacuum-cleaned, inspected, branded, and packaged (Gregg, 1974).

6.2.1.2 Wet-Mix Process

Figure 6.3 shows the major steps in the manufacture of wet-mixed molded brake linings. The name "wet mix" process is a misnomer and refers

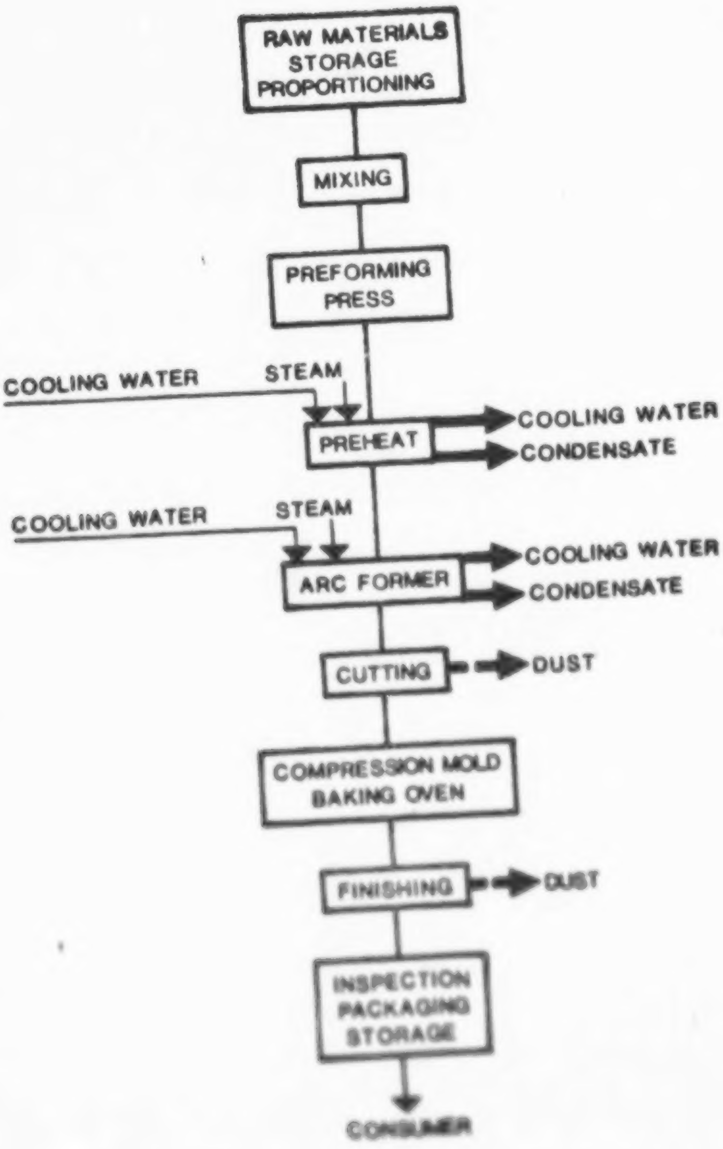
RAW MATERIALS
STORAGE
PROPORTIONING
MIXING
PREFORMING
PRESS
COOLING WATER
STEAM
PREHEAT
COOLING WATER
CONDENSATE
COOLING WATER
STEAM
ARC FORMER
COOLING WATER
CONDENSATE
CUTTING
DUST
COMPRESSION MOLD
BAKING OVEN
FINISHING
DUST
INSPECTION
PACKAGING
STORAGE
CONSUMER

Figure 6.2. Dry-Mixed Brake Lining Manufacturing Operations (Gregg, 1974)

to the use of a solvent. The ingredients of the molded lining are actually relatively dry. After weighing, they are mixed in a sigma blade mixer. The mixed ingredients are then sent to grinding screens where the particle size of the mixture is corrected. The mixture is conveyed to a hopper and is forced from the hopper into the nip of two form rollers which compress the mixture into a continuous strip of friction material. The strip is cut into the proper lengths and then arc-formed on a round press bar. The cutting and arc forming operations are done by separate units. The linings are then placed in racks and either air-dried or oven-dried to remove the solvent. An alternative process is to place the arc-formed linings in metal molds for baking in an oven. From the ovens, the linings are finished, inspected, and packaged (Gregg, 1974).

Molded clutch facings are produced in a manner similar to the wet-mixed process. The rubber friction compound, solvent, and asbestos fibers are introduced into a mixer churn. After the churn mixes the ingredients, the mixture is conveyed to a sheeter mill which forms a sheet or slab of the materials. The sheet is then diced into small pieces by a rotary cutter. The pieces are placed in an extrusion machine which forms sheets of the diced material. The sheets are cut into the proper size and then punch-pressed into doughnut-shaped sheets. The scraps from the punch press are returned to the extrusion machine. The punched sheets are placed on racks and sent to a drying oven and then a baking oven for final curing and solvent evaporation. The oven-dried sheets are finally sent to the finishing operations. Figure 6.4 illustrates the steps in the manufacture of molded clutch facings (Gregg, 1974).

6.2.2 Woven Products

Woven clutch facings and brake linings are manufactured of high strength asbestos fabric that is frequently reinforced with wire. The fabric is

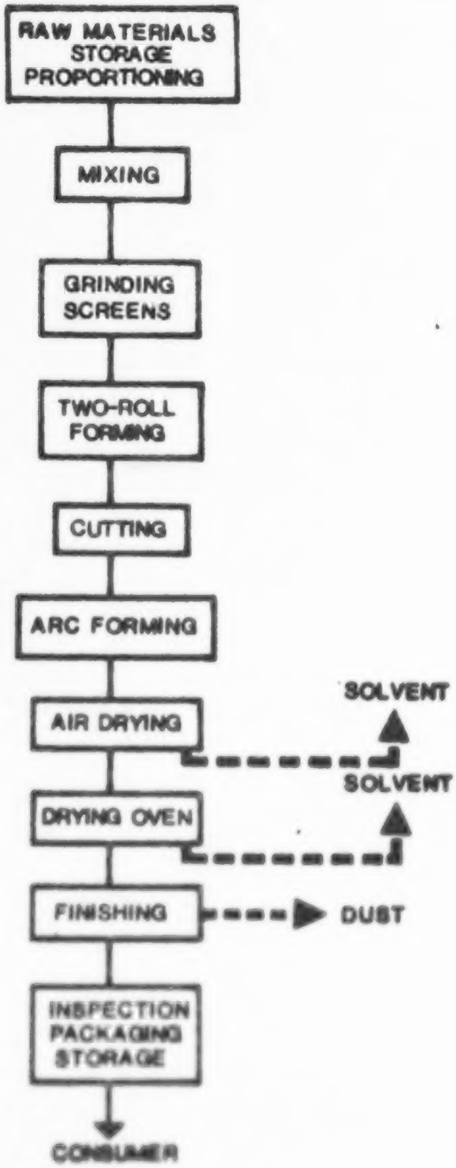
RAW MATERIALS
STORAGE
PROPORTIONING
MIXING
GRINDING
SCREENS
TWO-ROLL
FORMING
CUTTING
ARC FORMING
SOLVENT
AIR DRYING
SOLVENT
DRYING OVEN
FINISHING
DUST
INSPECTION
PACKAGING
STORAGE
CONSUMER

Figure 6.3. Wet-Mixed Molded Brake Lining Manufacturing Operations (Gregg, 1974)

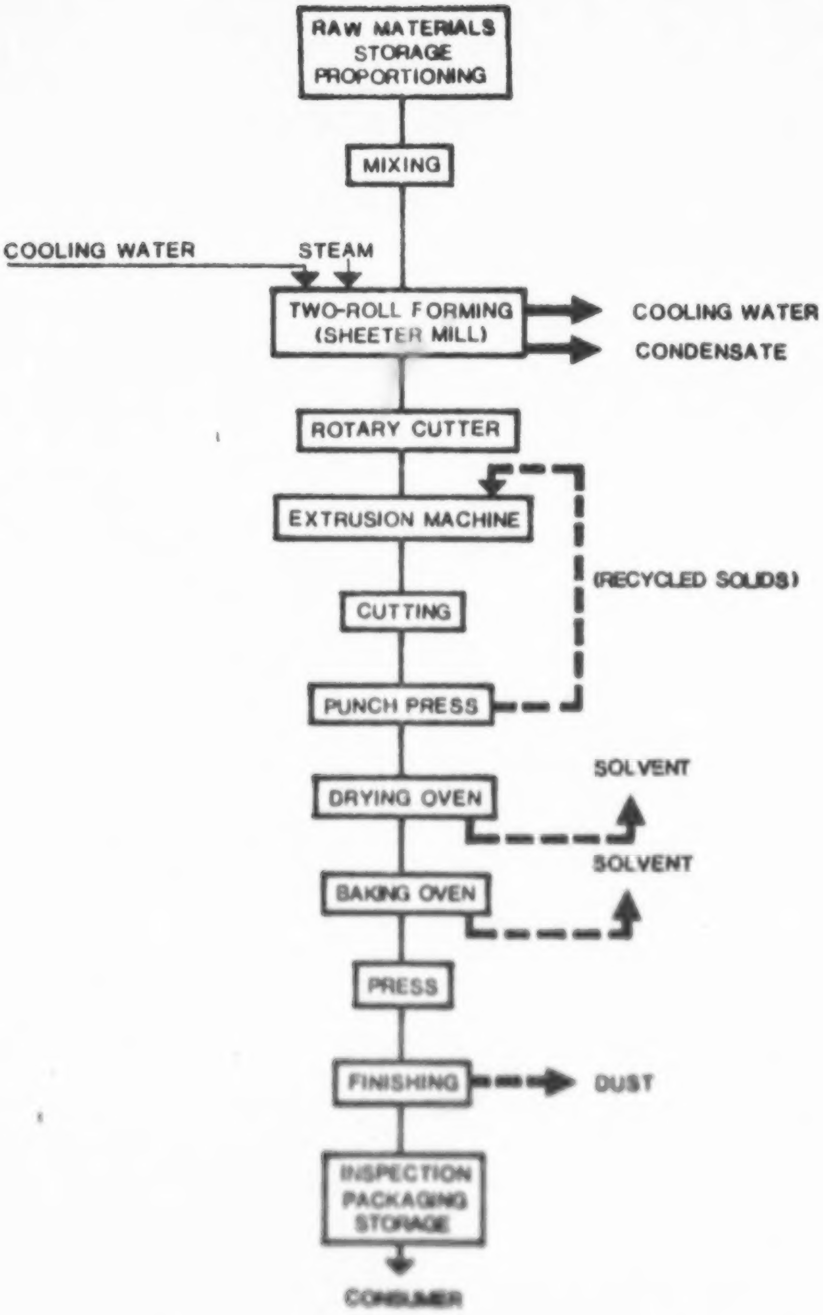
RAW MATERIALS
STORAGE
PROPORTIONING
MIXING
COOLING WATER
STEAM
TWO-ROLL FORMING
(SHEETER MILL)
COOLING WATER
CONDENSATE
ROTARY CUTTER
EXTRUSION MACHINE
(RECYCLED SOLIDS)
CUTTING
PUNCH PRESS
SOLVENT
DRYING OVEN
SOLVENT
BAKING OVEN
PRESS
FINISHING
DUST
INSPECTION
PACKAGING
STORAGE
CONSUMER

Figure 6.4. Molded Clutch Facings Manufacturing Operations (Gregg, 1974)

predried in an oven or by an autoclave to prepare it to be impregnated with resin. The fabric can be impregnated with resin by several techniques: 1) immersion in a bath of resin, 2) introducing the binder in an autoclave under pressure, 3) introducing dry impregnating material into carded fiber before producing yarn, and 4) imparting binder into the fabric from the surface of a roll. After the solvents are evaporated from the fabric, it is made into brake linings or clutch facings. Brake linings are made by calendering or hot pressing the fabric in molds. The linings are then cut, rough ground, placed in molds, and placed in a baking oven for final curing. Following curing, the lining is finished, inspected, and packaged (Gregg, 1974).

Figure 6.5 illustrates the manufacture of woven clutch facings. The treated fabric is cut into tape-width strips by a slitting machine. The strips are wound around a mandrel to form a roll of the fabric. The roll is pressed in a steam-heated press and then baked in an oven to cure the resin in the clutch facing. Following curing, the clutch facing is finished, inspected, and packaged (Gregg, 1974).

6.3 Composition of Friction Materials

Many raw materials, including some whose exact roles are regarded as proprietary knowledge, are used in varying quantities in the manufacutre of friction materials. The major, or foundation constituent, of practically all organic friction materials is asbestos fiber. The asbestos usually used in friction materials is chrysotile from Quebec or Vermont (Jacko and DuCharme, 1973); grades 3-7 are used; however, grades 5 and 7 account for nearly 82% of the total (Clifton, 1977). Asbestos is used because of its thermal stability, relatively high friction level, and reinforcing properties.

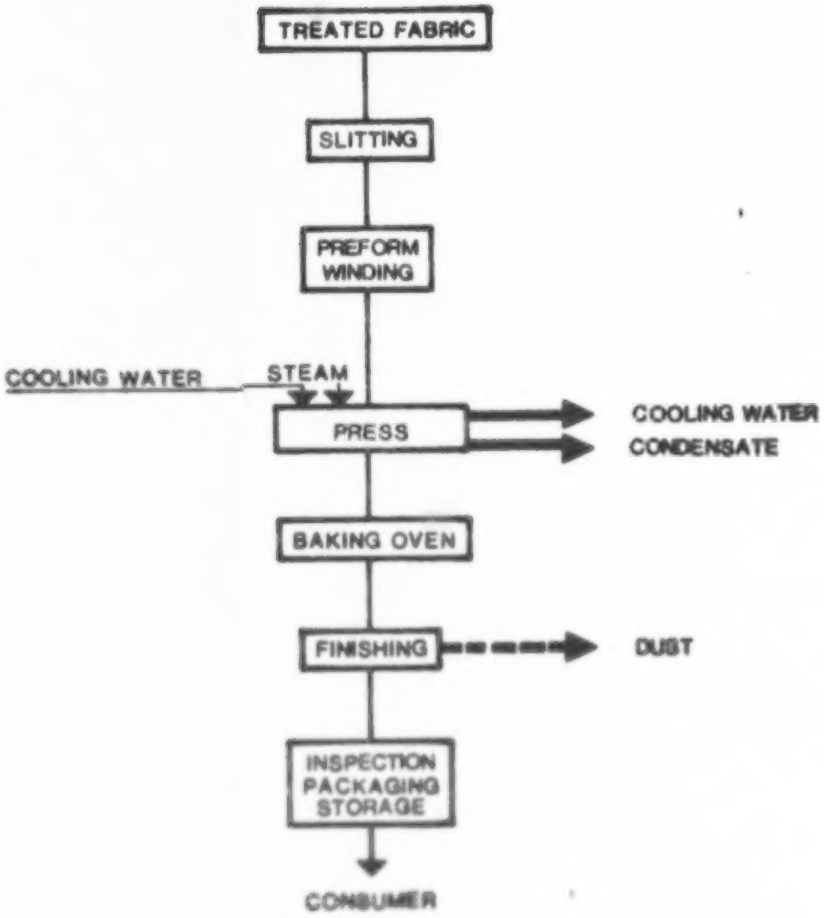
TREATED FABRIC
SLITTING
PREFORM WINDING
COOLING WATER
STEAM
PRESS
COOLING WATER
CONDENSATE
BAKING OVEN
FINISHING
DUST
INSPECTION PACKAGING STORAGE
CONSUMER

Figure 6.5. Woven Clutch Facings Manufacturing Operations (Gregg, 1974)

Asbestos alone does not offer all of the desired friction properties. Therefore, other materials, known as property modifiers, are added to the asbestos fibers. Modifiers are varied in type and content to provide desired levels of effectiveness, wear, fade, recovery, and noise. A binder is also added to hold the other materials together with adequate strength.

6.3.1 Binders

Table 6.3 lists binders and property modifiers which are used in automotive brake linings. The binders used in the automotive industry today are primarily phenolic-type resins which are noted for high binding efficiency and ability to withstand pyrolytic breakdown (Rohl *et al.*, 1976). They are prepared as the condensation product between the appropriate phenol (sometimes modified) and formaldehyde in the presence of an acidic catalyst to yield the novolak. When mixed with an appropriate curing agent, they polymerize at elevated temperatures to an insoluble, infusible mass (Jacko and DuCharme, 1973). Other resin systems in wide use are based on elastomers, drying oils, or combinations.

6.3.2 Property Modifiers

Perhaps the widest range of materials used in friction products are the property modifiers. Table 6.3 indicates the range and diversity of these modifiers. In general, property modifiers can be divided into two classes: non-abrasive modifiers and abrasive modifiers (Jacko and DuCharme, 1973).

6.3.2.1 Non-Abrasive Modifiers

Non-abrasive friction modifiers can be classified further as low friction and high friction. The most common and best known of the high friction materials is known as friction dust. This is a cured resinous material. The most frequently used variety is derived from cured or polymerized

Table 6.3. Binders and Property Modifiers In Automotive Brake Linings (Rohl *et al.*, 1976; Jacko and DuCharme, 1973; various patent literature; Bark *et al.*, 1975)

Binders	Property Modifiers	Use Function
Phenolic-type resins	Graphite	Lower friction coefficient and noise
Natural rubber	Coke	"
Buna N rubber	Coal	"
Nitrile rubber	Carbon black	"
Tire scrap	Gilsonite	"
Pitch		
Cork	Rottenstone (SiO_2)	Remove decomposition deposits
Gilsonite	Quartz (SiO_2)	"
Elastomers	Wollastonite ($CaSiO_3$)	"
Drying oils	Brass Chips	"
	Zinc and compounds	"
	Alluminum	"
	Limestone ($CaCO_3$)	Improve wear resistance
	Clays	"
	Silicas	"
	Barite	"
	Lead and compounds	Lubricant to prevent grabbing
	Friction dusts	See discussion in Section 6.3.2.1
	Antimony compounds	Not available
	Calcium compounds	"
	Copper and compounds	"
	Barium hydroxide	"
	Potassium dichromate	"
	Magnesium carbonate	"
	Iron oxide	"
	Cryolite (Na_6AlF_3)	"
	Fluorspar	"
	Cardolite	"
	Nickel	"
	Sulfur	"
	Molybdenum disulfide	Lubricant
	Calcium fluoride	Lubricant

cashew-nut-shell liquid, chemically a phenolic compound. When heated with hardening agents, such as hexamethylenetetramine or formaldehyde, it becomes sufficiently hard or polymerized to be granulated. Many other cured resinous or polymeric materials, some with fillers, are also used. Certain friction dusts are combinations of these materials and cashew resin. Ground rubber is normally used in particle sizes similar to, or slightly coarser than, those of the cashew friction dusts for noise, wear, and abrasion control (Jacko and DuCharme, 1973).

Carbon black, graphite, petroleum coke flour, or other carbonaceous materials may also be added as friction modifiers to lower the friction coefficient or to reduce noise. These materials are normally used in the form of fine powders or particles, although graphite is sometimes used in coarse particles or pellets. The amount of friction modifier added is dependent upon the properties desired in the final composite (Jacko and DuCharme, 1973).

6.3.2.2 Abrasive Modifiers

Abrasive modifiers, such as alumina and the silicas, are usually used in relatively small amounts and only in very fine particle sizes (generally 100 mesh or finer). Particle size is limited by the fact that large particles of such hard materials would groove and wear the mating surfaces. Minerals are generally added to improve wear resistance at minimum cost. Those most commonly used are ground limestone (whiting) and barytes (barium sulphate), though various types of clay, finely divided silicas, and other inexpensive or abundant inorganic powders may also perform this function. Such materials are inorganic in nature and tend to detract from noise properties and mating surface compatibility (Jacko and DuCharme, 1973).

Metals or metal oxides may also be added to perform specific functions. Brass chips are frequently found in heavy-duty friction materials where, as scavengers, they break up undesirable surface films. Zinc and aluminum are also used. Zinc chips, in relatively small amounts, can contribute significantly to recovery of normal performance following fade (Jacko and DuCharme, 1973).

6.3.3 Composition

The average composition of a typical automobile and truck brake lining is shown in Table 6.4a. Individual mixes may vary considerably from these averages.

Table 6.4a. Average Brake Lining Composition (Lunch, 1968)

(wt %)

Ingredient	Automobile	Truck
Asbestos	55	33
Resins and Polymers	28	48
Oxides and Pigments	9	16
Metals	3	2
Carbon, Graphite, etc.	5	1
	100%	100%

Manufacturers are very reluctant to release their exact compositions due to proprietary considerations. A search of patent literature reveals limited information, although several examples from the patent literature are given in Table 6.4b.

6.3.4 Summary

The tables and examples given in Section 6.3 have been included to illustrate the wide variety of compositions which are possible for fabrication of automotive and truck brake linings. Brake linings have been singled out

Table 6.4b. Brake Lining Compositions from Patent Literature

(wt %)

Example No. 1*	
Asbestos	55
Barite	10
Phenolic resin binder	20
Brass	5
Magnesium carbonate	8
Limestone	8
Organic calcium powder	10

Example No. 2**	
Asbestos	60
Phenolic resin	15
Nitrile rubber	3
Cashew dusts	12
Calcium fluoride	7
Copper iodide	3

Example No. 3***	
Asbestos	35
Barite	2.5
Graphite	7
Brass	13
Phenolic resin	7
Lead oxide	11.5
Buna N rubber	8
Naphtha	7
Copper sulfide	12.5
Methyl ethyl ketone	4

Example No. 4****	
Asbestos	50
Tarry residue	12
Barite	20
Phenolic resin	20
Graphite	2

---

* Sakata *et al.*, 1974 (Hitachi)
** Toyota Central Research and Development Labs, 1971
*** Keller, 1969 (Abex)
**** Mitchell, 1974 (duPont)

from the asbestos-friction products for examination because of their dominance of the asbestos-friction products market as shown in Table 6.1. When the variations of compositions are coupled with the variations of manufacturing process methods (as described in Section 6.2), it is possible to view a brake lining made by company A as substantially different from a brake lining made by company B, although the intended use applications may be the same. From this standpoint, it is entirely reasonable to speculate that asbestos emissions during automotive brake use may vary in concentration, depending upon composition and process manufacture of the individual linings.

6.4 Asbestos Emissions from Brake Lining Use

Asbestos has been identified in over 200 air samples taken from the atmosphere of 49 cities in the United States (Nicholson *et al*., 1973); asbestos was present in every sample taken. Asbestos has also been found in air samples from European cities (Holt and Young, 1973) and from air samples collected in Australia (Alste *et al*., 1976). The asbestos manufacturing industry may not be the source of the asbestos emissions found in urban air samples cited above. According to Holt and Young (1973), "the object of our investigations was only to determine whether asbestos fibres are present in the atmosphere of towns where there is no asbestos industry. The result was positive in every case."

The source of asbestos emissions, in the absence of asbestos mining and industry, is a matter of speculation. Holt and Young (1973) and Selikoff *et al*. (1972) suggest that the asbestos source may be construction which uses building materials made from asbestos. Alste *et al*. (1976) consider, as a source, that asbestos emitted from automobile brake linings is a "strong possibility." Alste *et al*. (1976) found that the air concentration of asbestos was much higher at points where considerable braking occurred, as compared to points of virtually no braking. This result is apparently in agreement with measurements made in New York City which found that the asbestos air concentrations contiguous to a toll booth were three to five times higher than background levels (Bruckman and Rubino, 1977; Nicholson et al., 1971). This subsection will consider the possibility of asbestos emissions from brake lining use.

6.4.1 Published Literature

A number of articles and publications (Rohl et al., 1976, 1977; Alste et al., 1976; Jacko and DuCharme, 1973; Jacko et al., 1973; Bush et al., 1972; Hatch, 1970; Hickish and Knight, 1970; Lynch, 1968) have discussed the asbestos emissions from the use of brake linings. Table 6.5 gives a brief summary of this published data in terms of methodologies and results. As can be seen from Table 6.5, there are important discrepancies in the results obtained.

6.4.1.1 Discrepancies in Asbestos Content of Emissions or Debris

Lynch (1968), Hatch (1970), Hickish and Knight (1970), Jacko and DuCharme (1973), and Anderson et al. (1973) reported figures in the range of 1% or less for the asbestos content of emissions or debris resulting from brake lining use. Bush et al. (1972) and Rohl et al. (1976, 1977) arrived at figures which are substantially higher, 44% and 2-15% asbestos content, respectively. While Alste et al. (1976) did not arrive at a percent figure, they did conclude that the major effect of braking appears to be separation of bunches of fibres and reduction of their average length, but not alteration of their crystal structure. This conclusion may certainly result in a relatively high asbestos content for wear debris.

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Table 6.5. Summary of Published Data - Asbestos Emissions from Brake Lining Use

Publication Source	Method Used to Collect Emission or Debris Samples	Method Used to Determine Asbestos Content of Emission Debris Samples	Asbestos Particle Size Distribution	Asbestos Content of Emission or Debris
Lynch, 1968	Laboratory simulations utilizing brake-testing machines or dynamometers. Samples collected on 0.8 μ pore size membrane filters.	Electron micrographs	Not discussed	<1%, except under severe-stress conditions
Hatch, 1970	A dust cloud was generated by using compressed air jets to remove dust from brake linings in an auto repair garage. Samples were collected by means of a hand pump located in center of dust cloud.	Not stated	94% of fibers fell in 2-5 μm length category. Only 6% were longer than 5 μm	~1%
Hickish and Knight, 1970	Samples were collected directly from debris remaining as brake dust and from membrane filters exposed during brake cleaning operations utilizing compressed air. Filter pore size is not given.	Not stated	Not discussed	1.6% and less
Bush et al., 1972	Laboratory simulations utilizing a disc brake assembly mounted on an inertial dynamometer. Samples were collected on suitable filter paper.	Neutron activation	Not discussed	~44% (this figure is not accurate; see discussion in Section 6.4.1.1)
Anderson et al., 1973	Laboratory simulations utilizing a disc brake assembly mounted on a dynamometer. Air samples of wear debris collected down wind of disc brake.	Transmission electron microscopy	Test results and procedures precluded a size distribution estimate	~0.02%
Jacko and DuCharme, 1973 (contains same data as Jacko et al., 1973)	Samples were generated by operating a standard American car under typical driving conditions in Detroit, Michigan. More abusive conditions, such as fade tests, were also included. Brake and clutch assemblies were enclosed by specially designed collectors. Samples were collected from 1) dropouts during use, 2) dust retained in lining assemblies, and 3) airborne samples collected on membrane filters.	Optical and electron microscopy	30% of fibers were from 0.25-0.50 μm in length; 60% were longer than 0.5 μm	0.25% overall average (an independent check done by Batelle Labs gave a figure of 0.171%)

Table 6.5. Summary of Published Data - Asbestos Emissions from Brake Lining Use (Cont'd)

Publication Source	Method Used to Collect Emission or Debris Samples	Method Used to Determine Asbestos Content of Emission Debris Samples	Asbestos Particle Size Distribution	Asbestos Content of Emission or Debris
Rohl et al., 1976	Ten samples of automobile brake drum dusts were collected from maintenance shops in the New York area.	X-ray diffractometry		2-15%; average of 3-6%
		Transmission electron microscopy, selected area electron diffraction, and electron microprobe analyses	80% of fibers were shorter than 0.4 µm length	Consistent with, but lower than, quantitative determination made by X-ray diffractometry; no percentages are given
Alste et al., 1976	Samples were taken from fresh and worn brake linings and from the atmosphere near a freeway.	Electron microscopy and electron diffraction	Majority were ≤ 2 µm in maximum linear dimension	No percent figure given; however, conclusion was that major effect of braking appears to be in separating bunches of fibres and reducing their average length, but not in altering their crystal structure
Rohl et al., 1977	This is basically a reprint of the Rohl et al., 1976 study with the inclusion of brake wear test samples obtained from Europe and Australia.			The mean weight percentage ranged from 1.4% in Australia to 2.5% in France

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The 44% figure computed by Bush et al. (1972) is based upon a neutron activation analysis, which is a technique for finding the elemental composition of a sample by irradiating the sample with neutrons, thereby causing the elements to become radioactive. Bush et al. is careful to point out that chrysotile asbestos is a magnesium silicate and neither magnesium or silicon are able to be determined utilizing the particular technique. Therefore, asbestos content of the wear debris was determined by means of a scandium concentration. Scandium was a trace element (∿ 4 ppm) present in the chrysotile used in the experiment. Neutron activation can be a very precise and useful technique for determining elemental composition; unfortunately, the asbestos content of any particular wear debris sample cannot be computed by an elemental analysis. Chrysotile asbestos is a unique crystal structure of a magnesium silicate (see Section 2.1); heat or other physical means can destroy this unique structure, thereby creating a different compound with different properties. However, the elemental composition of the different compound will be identical with chrysotile. Rohl et al. (1976) determined that the magnesium:silicon ratio of an asbestos friction material is the same before use and after use (as determined from wear debris via chemical analyses). Therefore, the 44% asbestos content figure computed by Bush et al. (1972) does not represent the asbestos content, but rather it represents the magnesium silicate content. When considering wear debris from friction materials, neither neutron activation nor chemical analyses are useable techniques for analysis of asbestos concentration.

The major conflict to be resolved is the high asbestos content suggested by Alste (1976) coupled with the 2-15% asbestos content figure obtained by Rohl et al. (1976, 1977) versus the 1% and less figures obtained by the remaining publication sources listed in Table 6.5. The difference of results appears to be based upon collection methodologies, analysis techniques, and interpretations.

6.4.1.2 Collection Methodologies and Particle Size Distribution

The first major consideration of methodology is the type of samples which were collected. Lynch (1968), Bush et al. (1972), and Anderson et al. (1973) collected laboratory samples produced by simulations, while other researchers listed in Table 6.5 collected samples from automobiles which were undergoing or had undergone actual driving conditions. Conditions encountered during actual use may not be totally reproducible in the laboratory; hence, the asbestos emission factors may be somewhat different. It would seem probable that samples collected from actual auto use may be more relevant to airborne emission potential than laboratory simulations.

Jacko and DuCharme (1973) used specially designed collectors which enclosed brake and clutch assemblies which allowed wear debris samples to be collected while the test car was being driven on the street. Rohl et al. (1976, 1977), Alste et al. (1976), Hickish and Knight (1970), and Hatch (1970) collected wear debris samples from automobiles in repair shops which perform brake maintenance.

Another area of consideration is the asbestos particle size distribution in the wear debris. Rohl et al. (1976) determined that approximately four-fifths of the wear debris fibers are shorter than 0.4 μm in length while Jacko and DuCharme (1973) found that 30% of the fibers were from 0.25-0.50 μm in length. According to Rohl et al., some of the discrepancies between their data and those of Jacko and DuCharme may be attributed to Jacko and DuCharme's use of lower magnification (22,000X vs. 42,000X), at which fibers shorter than 0.20 μm may not be easily seen or identified on the electron microscopic screen. Jacko (1978b) attributes the particle size distribution differences to a mechanical degradation technique utilized by Rohl et al. (1976) but not by Jacko and DuCharme (1973). Hatch (1970) also produced size distribution figures, finding that 94% of the fibers fell in a 2-5 μm length range; however, there is no indication that Hatch attempted to look for fibers shorter than 2 μm. Alste et al. (1976) found that the majority of particles, which consisted of small bundles of fibers, had a maximum dimension of ≤ 2 μm.

The best available data (Rohl et al., 1976; Jacko and DuCharme, 1973; Alste et al., 1976) indicates that a very high percentage of the number of fibers, but a small weight fraction, of asbestos present in brake lining wear debris is shorter in length than 2 μm, with a substantial portion shorter than 0.5 μm.

6.4.1.3 Analysis Techniques

Hickish and Knight (1970) fail to discuss analysis techniques used to determine the asbestos content in their wear debris and, also, do not fully describe collection methods. Under these circumstances, it is difficult to accept their results at face values. Hatch (1970) is deficient in analysis methodology also, although it appears that he used electron microscopy in sizing particles down to 2 μm. Since the Rohl et al. (1976), Jacko and DuCharme (1973), and Alste et al. (1976) studies are the best studies yet conducted on brake lining asbestos emissions, a closer examination of the three is warranted.

As seen from Table 6.5, Rohl et al. determined their 2-15% asbestos content from X-ray diffractometry (both continuous and step-scan modes were used). According to Jacko and DuCharme, asbestos is readily identified when alone or in simple mixtures at high concentrations by the following analytical methods: X-ray diffraction, thermal methods, microscopy, and infrared analysis. However, in complex mixtures, or at very low concentrations, the analysis for asbestos is very difficult. In brake wear debris, the problem is compounded because the reaction products of asbestos (forsterite, olivine, and dehydroxylated serpentine) have similar elemental ratios, and several non-fibrous minerals have similar X-ray diffraction patterns. The only sensitive method which can be used is microscopy. The accuracy of X-ray diffraction to determine the asbestos concentration of brake wear debris is beyond the scope of this report.

Rohl _et_ _al_. further verified chrysotile presence by transmission electron microscopy and selected area electron diffraction. "Chrysotile was found, both in fiber and fibril form, with unaltered structure and chemical composition. Its frequency of occurrence was consistent with, but lower than, the quantitative determination made by X-ray diffraction analysis. However, it should be noted that X-ray diffraction analysis is based on both free fibers and fibers present in clumps; the latter would obscure the presence of discreet fibers on electron microscopy study."

Alste _et_ _al_. (1976) determined the presence of chrysotile asbestos by electron microscopy and electron diffraction and concluded that the major effect of braking appears to be in separating bunches of fibers and reducing their average length but not in altering their crystal structure. This is an important result in terms of the following consideration: If only 15%, or downwards to less than 1%, of wear debris is asbestos, what happens to the major portions of the asbestos originally present in the brake lining? Lynch (1968), Hatch (1970), and Hickish and Knight (1970) present a prevalent theory that "hot spots" created during braking cause the local asbestos fibers to undergo thermal degradation which results in thermal metamorphosis of the asbestos into a different mineral, such as forsterite (olivine). Jacko and DuCharme (1973) found that 20-40% of the wear debris composition was olivine. However, according to Alste et al. (1976) concerning wear debris from brake linings, "there was no indication from the diffraction pattern of the presence of forsterite;" this result was in agreement with Rohl et al. (1976) who also could not verify the presence of forsterite. Jacko (1978c) did find a reduction of asbestos and the formation of olivine (a form of forsterite) on frictional heat-affected layers using a combination of X-ray diffraction and thermogravimetric analysis. Rohl et al. (1976) and Jacko and DuCharme (1973) discussed other forms of brake lining wear, in addition to thermal wear, such as abrasive wear and macroshear wear. However, the end result is probably this: the asbestos present in the original brake lining, excluding the asbestos which is emitted in the wear debris, is converted by thermal or other physical processes into magnesium silicates or other recrystallized magnesium silicate structures different from asbestos. In addition to unaltered chrysotile fiber in the wear debris, Rohl et al. (1976) observed partially altered and completely recrystallized fibers. Holt and Young (1973) reported that some of the asbestos fibrils collected in European city air appeared to have been heated.

6.4.1.4 Other Considerations

The Rohl et al. (1976, 1977) studies are based upon a wider and more random sampling than that of Jacko and DuCharme (1973).

Rohl et al. selected wear debris samples from ten random automobiles undergoing brake maintenance in New York and 29 samples from Australia and Europe, while Jacko and DuCharme's wear debris samples came only from original auto equipment, a partial relining, and a relining for the car tested. Alste et al. (1976) also collected random samples of wear debris from an auto repair shop, but apparently from only a few cars at most (a much smaller sampling than Rohl et al.).

Neither Rohl et al. (1976), Jacko and DuCharme (1973), nor Alste et al. (1976) considered, or tested, brake linings manufactured by different companies, different technical processes, or different compositions in any systematic manner which would be representative of the entire brake lining industry. Jacko and DuCharme (1973) did use brake linings manufactured by five different manufacturers, including original and replacement equipment; however, only "class A" friction materials were used. Class A materials refer to the better quality, longer wearing friction materials, as opposed to class B materials, which have inferior wear characteristics. Jacko (1978b) suspects that the wear debris collected by Alste et al. (1976) may have resulted from wear of class B brake linings; however, there is no confirmation of this supposition.

There has been no experimental study conducted which can confirm or refute the supposition that brake linings made by different companies, processes, and compositions may contribute varying amounts of asbestos emissions into the environment.

It has been suggested by several industry spokesmen that class A material would contribute a smaller asbestos emission to the environment than class B material. This has not been confirmed experimentally.

Industry spokesmen also believe that a larger percentage of foreign cars imported into the U.S. are equipped with class B brake linings than cars manufactured domestically.

A recent study by Seshan and Smith (1977) has supported the work of Rohl et al. (1976) and Alste et al. (1976) and contradicts the work of Jacko and DuCharme (1973). Seshan and Smith (1977) examined automobile brake drum dust using transmission electron microscopy. They found unaltered chrysotile fibre fundles with some phenolic binder and deformed chrysotile which were difficult to determine by selected area electron diffraction. However, they were able to study the deformations in detail using high resolution dark-field microscopy and suggested that dark-field microscopy be used to identify the sources of asbestos fibres found in air pollution samples. These investigators also examined the brake drum dust with light optical microscopy (LOM) and X-ray diffraction (XRD) and found little (less than 1%) chrysotile and no forsterite which they concluded was due to the fact that the fibre sizes and concentrations were below the limits of detection for LOM and XRD.

6.4.2 Emission Quantities

Table 6.6 gives the estimated annual asbestos emissions for vehicles as computed by Jacko and Du Charme (1973). These figures are based, in part, upon Jacko and DuCharme's figure of less than 1% (∿0.2%) asbestos content of emission debris. They also made the following estimations:

(1) The total amount of asbestos contained in all of the automotive brake friction materials sold each year is about 103 million pounds which corresponds to ∿118 million pounds prior to grinding and drilling.

(2) The total amount of asbestos contained in all automotive clutch friction materials sold each year is about 4.5 million pounds.

Table 6.6. Estimated Asbestos Emissions* by Jacko and DuCharme (1973) from Vehicles

	Number of Vehicles	Total Annual Asbestos Emissions (lb)	Distribution of Total (lb)		
			Drop-Out	Airborne	Retention
Passenger Cars	96,400,000	60,400	49,470	2,230	8,700
Light Trucks	17,100,000	32,300	28,420	940	2,940
Medium Trucks and Buses	2,600,000	16,300	14,330	470	1,500
Heavy Trucks	1,200,000	32,900	28,920	950	3,030
Miscellaneous (motorcycles, trailers, etc.)	6,615,000	16,300	14,330	470	1,500
Totals		158,200	135,470	5,060	17,670
Percent of Total			85.6	3.2	11.2

* Includes both brake linings and clutches

Table 6.7. Estimated Asbestos Emissions from Vehicles Using Rohl _et_ _al_. (1976) Figures for Asbestos Content of Wear Debris

Asbestos Content of Wear Debris	Total Annual Asbestos Emissions (lb)	Distribution of Total (lb)		
		Drop-Out	Airborne	Retention
2% (low)	1,520,000	1,300,000	49,000	171,000
15% (high)	11,400,000	9,800,000	360,000	1,280,000
4.5% (median of average 3-6%)	3,420,000	2,930,000	110,000	380,000

(3) The combined total of brake and clutch friction material worn away annually is 123.6 million pounds (117 (brakes) + 6.6 (clutches) = 123.6). Assuming an average asbestos content of 60%, the amount of asbestos worn away as friction material wear debris is ∿74 million pounds.

Based upon available data from other sources (Clifton, 1977; U.S. Bureau of the Census, 1972, 1975), the estimations made above are quite reasonable and are probably good figures to use in emission computations.

Table 6.7 lists the estimated asbestos emissions using the Rohl _et_ _al_. (1976) figure for the asbestos content of wear debris. Computations were made using the same assumptions and method as Jacko and DuCharme (1973); the only variation is the use of different asbestos content percentages. Rohl _et_ _al_. (1976) arrived at an average asbestos content figure of 3-6% (therefore, a median of 4.5% is listed in Table 6.7) and high-low values of 2-15%.

A comparison of Table 6.6 and 6.7 reveals that the total annual asbestos emissions reported in Table 6.7 (4.5% median) is nearly 22 times higher than the total reported in Table 6.6. The focal point of the difference is the percentage of asbestos which survives in the wear debris.

Jacko and DuCharme (1973) determined that approximately 3% of the asbestos emission become airborne. Based upon sample concentrations collected at freeway exits, Alste _et_ _al_. (1976) concluded that only a small fraction of the total dust formed becomes airborne, which is consistent with Jacko and DuCharme (1973) and Anderson _et_ _al_. (1973).

6.4.2.1 A Hypothetical Calculation

As mentioned earlier in Section 6.4, asbestos fibers have been monitored in ambient air samples by Holt and Young (1973), Alste _et_ _al_. (1976), and Nicholson _et_ _al_. (1973). Selikoff _et_ _al_. (1972) monitored ambient concentrations of asbestos in the New York City area and determined the following concentrations:

Site	Concentrations (ng/m^3)
Manhattan	25-60
Bronx	25-28
Brooklyn	19-22
Queens	18-29
Staten Island	11-21
Philadelphia	45-100
Ridgewood, N.J.	20
Port Allegany, Pa.	10-30

Bruckman and Rubino (1975) reported that asbestos levels in non-urban and remote non-urban air are typically less than 1 ng/m^3, while urban air usually has levels below 30 ng/m^3. From thirty selected monitoring sites in Connecticut, Bruckman and Rubino (1977) found the following concentrations:

1) less than 10 ng/m^3 in areas removed from emission sources
2) above 30 ng/m^3 near each of four industrial users
3) 10 ng/m^3 to 25 ng/m^3 adjacent to toll plazas where autos commonly apply brakes

The above data gives a general idea of the magnitudes of various background levels of ambient air concentrations of asbestos. The following hypothetical case is intended to project a theoretical magnitude of contamination from friction material use.

Hypothetical Case: This calculation attempts to estimate the levels of asbestos which may be added to urban environments as a result of wear from automobile brake linings. As noted in Tables 6.6 and 6.7, the amount of asbestos emitted by brake linings has been estimated to range from 2.5 to 55 tons airborne per year. The calculation below will assume a nationwide emission average of 10 tons per year. New York City will be considered because of available air monitoring data. New York City has a population of approximately 7.9 million people and an area of roughly 300 sq. miles. It is assumed that friction material use follows population; therefore, of the estimated 10 tons of emissions from brake linings, NYC would be responsible for:

$$\frac{7.9 \text{ million (NYC pop.)}}{210 \text{ million (US pop.)}} \text{ X } 10 \text{ tons} = 0.376 \text{ tons} = 3.4 \text{ X } 10^{14} \frac{\text{ng}}{\text{yr}}$$

This value of $3.4 \text{ X } 10^{14}$ ng/yr translates into an emission of roughly $9.34 \text{ X } 10^{11}$ ng/day. The volume of air 1000 ft. above street level over NYC is about $2.5 \text{ X } 10^{11} \text{ m}^3$. It is assumed that the daily emissions of asbestos become equally distributed throughout the air 1000 ft. above street level. Therefore, the ambient air concentration of asbestos which results from daily brake emissions would be:

$$\frac{9.34 \text{ X } 10^{11} \text{ ng/day}}{2.4 \text{ X } 10^{11} \text{ m}^3} = 3.7 \text{ ng/m}^3$$

The resulting estimate is on the same order of magnitude as available monitoring data. It should be remembered that this calculation is totally theoretical and is not intended as proof that brake emissions are responsible for all asbestos emissions monitored in ambient air. Many other factors need consideration in terms of brake emissions to air, such as weather effects upon airborne fibers and actual distribution patterns from emission sources. The potential for the sizes of particles emitted to remain airborne is a major consideration.

6.4.3 Human Exposure to Asbestos Emissions During Brake Lining Maintenance and Repair

In the United States, an estimated work force of at least 900,000 auto mechanics and garage workers is potentially exposed to asbestos in the servicing of both brake and clutch linings (Rohl *et al.*, 1976).

Measurable concentrations of asbestos fiber have been observed and reported in the work environment of workmen involved with brake and clutch linings maintenance and repair (Hickish and Knight, 1970; Hatch, 1970; Boillat and Lob, 1973; Rohl _et al_., 1976).

When a vehicle is brought into a repair shop for brake lining inspection or replacement, the wheel is removed and the loose dust is removed from the drums and back plates, generally by means of a compressed air jet. A cloud of dust is produced by this air jet which is visible for several minutes. Table 6.8 lists the fiber concentrations which were measured as a result of the dust cloud by the most relevant study (Rohl _et al_., 1976) to American standards of exposure; also given are concentrations measured for common truck servicing operations.

The result of the Rohl _et al_. (1976) study indicates that it is common for OSHA asbestos-fiber concentration standards to be exceeded during brake cleaning operations. It should be noted that fiber counts made during this study were in accordance with procedures adopted by OSHA. Essentially, the analysis consists of counting fibers 5 to 100 μm using phase contrast microscopy at a magnification of 400X.

Section 6.4.1.2 revealed that most of asbestos present in wear debris is much smaller than 5 μm. Rohl _et al_. (1976) estimated that 80% of the fibers present are shorter than 0.4 μm. Accepting these results, it is obvious that the asbestos exposure during brake servicing may be a great deal higher than is indicated by OSHA test standards.

Table 6.8. Asbestos Concentration During Automobile and Truck Brake Service* (Rohl *et al.*, 1976)

Operation	Distance (ft)	Number of Samples	Fiber Concentration (fibers/ml) Mean	Fiber Concentration (fibers/ml) Range
Auto - Blowing dust out of brake drums with compressed air	3-5	4	16.0	6.6-29.8
	5-10	3	3.3	2.0-4.2
	10-20	2	2.6	0.4-4.8
Truck - Renewing used linings by grinding	3-5	10	3.8	1.7-7.0
Truck - Beveling new linings	3-5	5	37.3	23.7-72.0

* Fibers 5-100 μm in length, counted by optical microscopy.

6.5 Alternatives to Asbestos as a Friction Material

6.5.1 The Role of Asbestos in Friction Linings

Originally, automotive brake linings were made from a cotton textile material which was impregnated with drying oils and cured to form a strip of material which was flexible, conformable, and mechanically very strong. The main purpose of the drying oil was to protect the cotton from attack by atmospheric oxygen, which, even at the temperatures reached by early brakes, would have resulted in burned cotton had its surface been exposed to the air. As brake operating temperatures increased, it was found that cotton started to degrade and lose its strength even though still protected from oxygen attack. In other words, the cotton suffered thermal degradation instead of oxidative degradation (Hatch, 1970).

Around 1910, a technological breakthrough was achieved when it was discovered that asbestos could be woven and used to replace cotton because asbestos neither burns nor loses its strength below about 500°C. When braking operations became more severe, in the 1940's, brake linings began to be manufactured by moulding powdered resins with short asbestos fibers. This made possible the inclusion of various property modifiers to aid in the braking operations (Hatch, 1970). As described in Section 6.2, this is the current method of brake lining manufacture.

Any alternative material to asbestos in brake linings has to compete with asbestos's properties of strength, high temperature protection, insulation, and good frictional properties.

6.5.2 Alternatives in Brake Linings

At this time, there are no commercially available, asbestos-free brake linings intended for use in automobiles with drum brakes (Aldrich, 1977;

Rosenburg, 1977). This is not the case when considering disc brake pads, as will be explained later. Currently, nearly all of the major brake lining manufacturers are engaged in research and testing programs to develop asbestos-free drum brake linings for automobiles; limited commercial success has been achieved only with semimetallic friction material. It should be noted that, if by "alternative" we mean a new or better fiber which might shortly be available as a replacement for asbestos in conventional brake linings, the chances are actually quite remote.

The possible asbestos alternatives which are being tested and considered are discussed below (Hatch, 1970; Aldrich, 1977; Rosenburg, 1977):

(1) Glass Fiber - overall strength is lower than that of asbestos, but strong enough for friction material applications. Unfortunately, at the temperatures reached by braking operations, glass fiber melts, even in depth below the operating surface.

(2) Steel Wool - compared to asbestos, the overall strength is lower and the cost is much higher. In addition, the material hardness of steel wool damages the brake drums.

(3) Mineral Wools - overall strength is very low and brittle to the extent of limiting mixing processes.

(4) Carbon Fiber - the main properties of carbon fibers are generally good, but still somewhat inferior to asbestos. A major consideration is the cost, which is a great deal more than asbestos.

(5) Sintered Metals and Cermets - these materials are now being used to manufacture brake linings for railroad cars and airplanes. Eventually, these materials may be developed into practical applications for automobiles. At this time, the wear-resistance is not good enough for automotive uses and the cost is too high.

There are two good reasons why the industry is attempting to develop asbestos-free products. First, there is the possibility of a governmental ban on asbestos applications which emit asbestos fibers into the atmosphere. And secondly, asbestos-free manufacture would eliminate the need for asbestos-environmental control devices in the workplace and would eliminate a health hazard to employees, thereby eliminating a substantial expense.

6.5.3 Alternatives in Disc Brake Pads

It is purely fortuitous that the friction materials used in disc brakes are designed to a stronger shape than in drum linings; that is, more or less square or circular pads of considerable thickness are supported by a metal plate of adequate thickness. Therefore, the friction material does not have to stand up to handling during assembly, does not have to withstand riveting, and could, from the point of view of bulk mechanical strength alone, be made without a high loading of fibrous reinforcement of any kind. There remains, however, thermal shrinkage and thermal shock, and in order to prevent the formation of tensile cracks normal to the operating surface, a percentage of asbestos fibre is still retained (Hatch, 1970).

Nevertheless, it cannot be said that the use of asbestos in disc brake pads remains a technical necessity (Hatch, 1970); in fact, commercially available disc pads have been developed for automotive uses which do not use asbestos (Aldrich, 1977). Table 6.9 lists a typical composition for this asbestos-free disc pad. Cost of the asbestos-free pad is somewhat higher than the asbestos pad.

Table 6.9. Asbestos-Free Composition of a Disc Brake Pad (Aldrich, 1973)

	(vol. %)
Carbon	45
Iron Powder	25
Steel Fiber	10
Phenolic Resin	20

(manufactured by common methods)

6.5.4 Alternatives in Clutches

Borg-Warner Corporation, a major manufacturer of clutches, is currently engaged in the testing of asbestos-free friction materials intended for use in clutches (Rosenburg, 1977). The asbestos-free materials being tested have been developed by the major friction-material producers such as Raybestos-Manhattan and Abex. To date, none of the alternatives tested have been as good as asbestos.

6.6 Quantities of Asbestos Released to the Environment from Manufacture

Listed below in Table 6.10 are the estimated quantities of asbestos released to the environment from asbestos friction products manufacture. The estimates in Table 6.10 are not intended to be considered precise quantities. The estimates are based upon available data and engineering assumptions and are intended only to project a general magnitude of release.

Table 6.10. Estimated Annual Environmental Release of Asbestos from Friction Material Manufacture (SRC estimate)

	Quantity (short tons)	Comment
To waste dump or landfill:		
Baghouse fine and product scraps	8,130	Mostly free-fibers*
Wastewater solids from air scrubbers	6.7	Wet free-fibers*
To water:		
Wastewaters from air scrubbers	0.3	Free-fibers*
To air:		
Baghouse emissions	0.61-6.0	Free-fibers*
Air scrubber emissions	0.14	Free-fibers*

* These "free-fibers" may be coated with resin, however, by "free" the intention is to indicate a potentially respirable fiber.

The estimates in Table 6.10 were derived by methods which are explained in the following subsections.

6.6.1 Release from Baghouses and Product Scraps

Jacko and DuCharme (1973) have reported that the amount of asbestos contained in all of the automotive brake friction materials sold each year is about 103 million lbs., which corresponds to about 118 million lbs. prior to grinding and drilling. This indicates that approximately 12.7% of the asbestos is lost to product scraps. The grinding and drilling of brake linings during manufacture can release as much as 30% of the lining material as waste (EPA, 1974). Even with the relatively high price of asbestos fiber, the asbestos contained in product scraps is not recovered for reuse (Gregg, 1974). Once the resin has set up, it is not regarded as economical to break it down to salvage the fiber. These wastes are normally disposed to landfills or waste piles.

In most cases, the emissions from grinding and drilling operations are collected in baghouses (EPA, 1974). These baghouse wastes can amount to as much as 13.5 tons per month for a plant producing 40,000 shoes per day (EPA, 1974). To determine the industry-wide quantity of asbestos disposed from baghouses and product scraps, the following assumptions are made: 1) about 12.7% of the total asbestos consumed in friction materials is lost to scraps and, 2) about three-fourths of this total is collected in baghouses and the remaining one-fourth is collected by vacuum cleaning operations or as damaged product. Based upon a total asbestos consumption of 64,000 tons for all friction materials in 1976 (Clifton, 1977), the amount of asbestos lost to product scraps would be about 8,130 tons. Baghouse collections would roughly amount to 6,100 tons and the other scraps would amount to roughly 2,030 tons. Virtually all of the asbestos collected in baghouses is in a potentially respirable form. Disposal operations of these baghouse wastes can potentially release fibers into the atmosphere (EPA, 1974). It is virtually impossible to quantify the amount of asbestos fibers released during disposal operations without monitoring data, of which there are none.

In most of the plants making friction materials, air emissions are controlled by baghouses; however, in a few plants, wet dust collectors are used and a wastewater results (Gregg, 1974). Asbestos releases from wet dust collection are discussed in the next subsection.

The efficiency of an asbestos baghouse collector, in terms of atmospheric emissions, has been monitored to have an efficiency of nearly 99.99% (Siebert et al., 1976). Applying this efficiency to the estimated quantity of 6,100 tons of asbestos collected by baghouses indicates that the asbestos fiber emissions to the atmosphere would be 0.61 tons annually. However, in Section 7.3.1, a baghouse emission factor has been developed which estimates that 1.34 lbs. of asbestos fibers are emitted per year per each 100 CFM rating. The exhaust air flow of a medium size friction material plant has been estimated to be in the neighborhood of 30,000 CFM (Gregg, 1974). Therefore, using the 1.34 lb. emission factor indicates that a medium size plant would emit about 400 lbs. of asbestos fibers each year. Table 6.2 lists over 30 friction material plants; therefore, this method predicts that roughly 6 tons of fibers would be emitted to the atmosphere industry-wide. As explained in Section 7.3.1, the 1.34 lb. emission factor is a "worst possible" case. The difference in estimates, 0.61 tons and 6.0 tons, is significant. There are not enough monitoring data available to make a precise estimate.

6.6.2 Release from Wet Dust Collection

Process wastewaters containing asbestos fibers are not generated by friction material manufacturing operations. However, waters used to clean fibers and particulates from air do contain asbestos, and these wastewaters are released by some plants. Wet dust collection is rarely used in the asbestos industry. Gregg (1974) identified only four friction material manufacturing plants that discharge wastewaters from wet dust collection. At all of the known plants, the wastewaters are clarified before discharge to surface waters. Currently, the number of plants using wet dust collection is not known; therefore, the estimates projected below are based upon Gregg's (1974) data.

The effluent waste load from wet dust collection for a typical plant is estimated to be 25 lbs. of suspended solids per day (Gregg, 1974). Assuming the suspended solids are about 50% asbestos (because asbestos is roughly 50% of the friction material's raw content) and an average work year of 50 weeks at 5.5 days per week, then about 3,450 lbs. of asbestos are collected by wet collection each year at a typical plant. Four plants would collect about 13,800 lbs. or roughly 7 tons of asbestos fibers. Clarification may remove approximately 95% of the suspended solids. The sludge collected from clarification would therefore contain about 6.7 tons of asbestos fibers; this sludge is disposed of in landfills. The clarifed water released to surface waters would contain about 0.3 ton of asbestos.

Wet-type air scrubbers normally operate in the range of 98% efficiency. Therefore, based upon a collection of 7 tons, these wet dust collectors would emit about 0.14 ton of fibers into the atmosphere.

7.0 ASBESTOS-CEMENT PIPE

Asbestos-cement pipe, which was developed about 60 years ago, is a durable, inexpensive pipe material extensively used in underground applications. Asbestos-cement (A-C) pipe is resistant to corrosion, both internally and externally, has high enough strength to withstand pressure pumping, and does not rust and cause discoloration of water.

The two major applications for A-C pipe are water distribution systems and sewer service. Small amounts of A-C pipe are used as telephone and electrical wire conduit and air ducting. It is estimated that roughly 70-75% of all the A-C pipe produced is used for water supply with sewer pipe accounting for 20-25% of all uses nationwide (Jackson, 1977). In the eastern United States, A-C sewer pipe currently outsells A-C water pipe by approximately three-to-one; however, in most other sections of the country the water pipe outsells the sewer pipe by three-to-one (Gresham, 1977; Lawless, 1977). This is due primarily to factors of climate and topography and the fact that the major water supply lines in the East have been in existence for years, whereas population expansion in other sections of the country has created a demand for new water supply systems. The largest markets for all types of A-C pipe are west of the Mississippi River (Jackson, 1977), as this is the area of the country in which the newer population centers are forming.

A-C pipe is produced in sizes ranging from 4 to 32 inches in diameter (Daly et al., 1976). The water supply pipe, a pressure pipe, has a somewhat thicker and stronger casing than the sewer pipe. Much of the water supply pipe is pressure-tested before shipment.

In 1974, an estimated 1.5 million miles of A-C pipe were in service worldwide, of which more than 200,000 miles were in the U.S. (Olson, 1974). Also in 1974, it was estimated that over 30% of all the water distribution pipe being sold in the U.S. was made of asbestos-cement (Johns-Manville, 1974). Currently (1977), it is estimated that roughly a quarter of a million miles of A-C pipe are in service nationwide with approximately 10 to 15 thousand miles of new pipe being produced each year (Jackson, 1977). Current figures for A-C pipe's market share of the water distribution and sewer market are not available; however, it is generally thought that the water distribution share has not changed significantly from the 1974 figure given above.

7.1 Use Quantity, Shipment Values, and Industrial Firms

U.S. demand for asbestos fiber in A-C pipe has ranged from 134 to 222 thousand short tons during the 1967-1976 period; in 1976, about 140 thousand tons were consumed for this purpose (Tables 4.9 and 4.10, p. 46). According to the 1976 figures, about 19.3% of the total U.S. market for asbestos was consumed in the production of A-C pipes. This is the second largest single use of asbestos fiber; roofing is the largest use.

The trend in the value of shipments of A-C pipe is shown in Table 7.1. A growth rate of five to seven percent has been projected for the A-C pipe market in the next three to seven years (Igwe, 1974). However, industry spokesmen indicate that the market for A-C pipe is, at present, stable (Jackson, 1977; Gresham, 1977). Significant increases or decreases in sales are not projected in the foreseeable future.

Table 7.2 lists the U.S. manufacturers of A-C pipe along with their respective sales in 1975. The four companies (13 plant locations) listed in

Table 7.1. Shipment Value and Quantity of Asbestos-Cement Pipe
(U.S. Bureau of the Census, 1972)

		Total Product Shipments, including interplant transfers					
		1975*		1972		1967	
SIC Product Code	Product	Quantity (10^3tons)	Value ($ million)	Quantity (10^3tons)	Value ($ million)	Quantity (10^3tons)	Value ($ million)
	Asbestos-Cement Pdts.						
32927 73	Pipe, conduit, ducts	900	197	870.1	143.3	840.1	118.6
32927 75	Pressure pipe						

*SRC Estimates

Note: All dollar values are actual values for that year.

Table 7.2. Major U.S. Manufacturers of Asbestos-Cement Pipe

Manufacturer	Plant Location	Estimated 1975* Sales of Asbestos-Cement Pipe (Millions of Dollars)
Johns-Manville	Manville, NJ	$78.0
	Long Beach, CA	29.0
	Waukegan, IL	15.0
	Denison, TX	14.4
	Green Cove Springs, FL	5.7
	Stockton, CA	--
Certain-Teed Corp.	St. Louis, MO	10.4
	Hillsboro, TX	8.7
	Ambler, PA	7.2
	Santa Clara, CA	4.6
	Riverside, CA	2.2
CAPCO (Cement-Asbestos Products Co., Div. of ASARCO)	Van Buren, AR	8.7
	Ragland, AL	4.3
Flintkote	Ravena, OH**	8.7
	TOTAL	196.9

*Economic Information Systems, Inc., SRC Estimates

**Closed 1976

Table 7.2 account for more than 95% of the total A-C pipe production in the U.S. (SRC estimate). Johns-Manville is clearly the industry leader in the production and sales of this product.

7.2 Manufacturing Process Technology

A description of the manufacturing process is included here to identify the sources from which asbestos is released to the environment from the process. Figure 7.1 gives the graphic illustration.

Asbestos-cement pipe normally contains from 15-25% asbestos by weight, usually of the chrysotile variety. Carton (1974) indicates an asbestos content range of 10-70%; however, such extremes are used for specialty items only. In 1976, 83.5% of the total amount of asbestos used in A-C pipe was chrysotile, 14.5% was crocidolite, and 2% was amosite (Clifton, 1977). Crocidolite is used in sewer pipe to increase production through faster filtering rates. Portland cement content varies from 25-70%. The remaining raw material, from 5-35%, is finely ground silica. Finely ground solids from damaged pipe are used by some plants as a filler material, up to 6% (Carton, 1974). The average asbestos content of asbestos-cement pipe, by weight, can be calculated to be about 18%. This figure was derived by comparing the total A-C pipe shipments in 1972, 870.1 thousand tons (Table 7.1), with the total of asbestos used in A-C pipe production in 1972, 154 thousand tons (Table 4.9, p. 46). Harwood and Ase (1977) have reported an average asbestos content figure of 25%, while Jackson (1977) has indicated that the asbestos content is normally below 20%.

The manufacturing steps for the production of A-C pipe may vary slightly from plant to plant; however, the general overall operations are

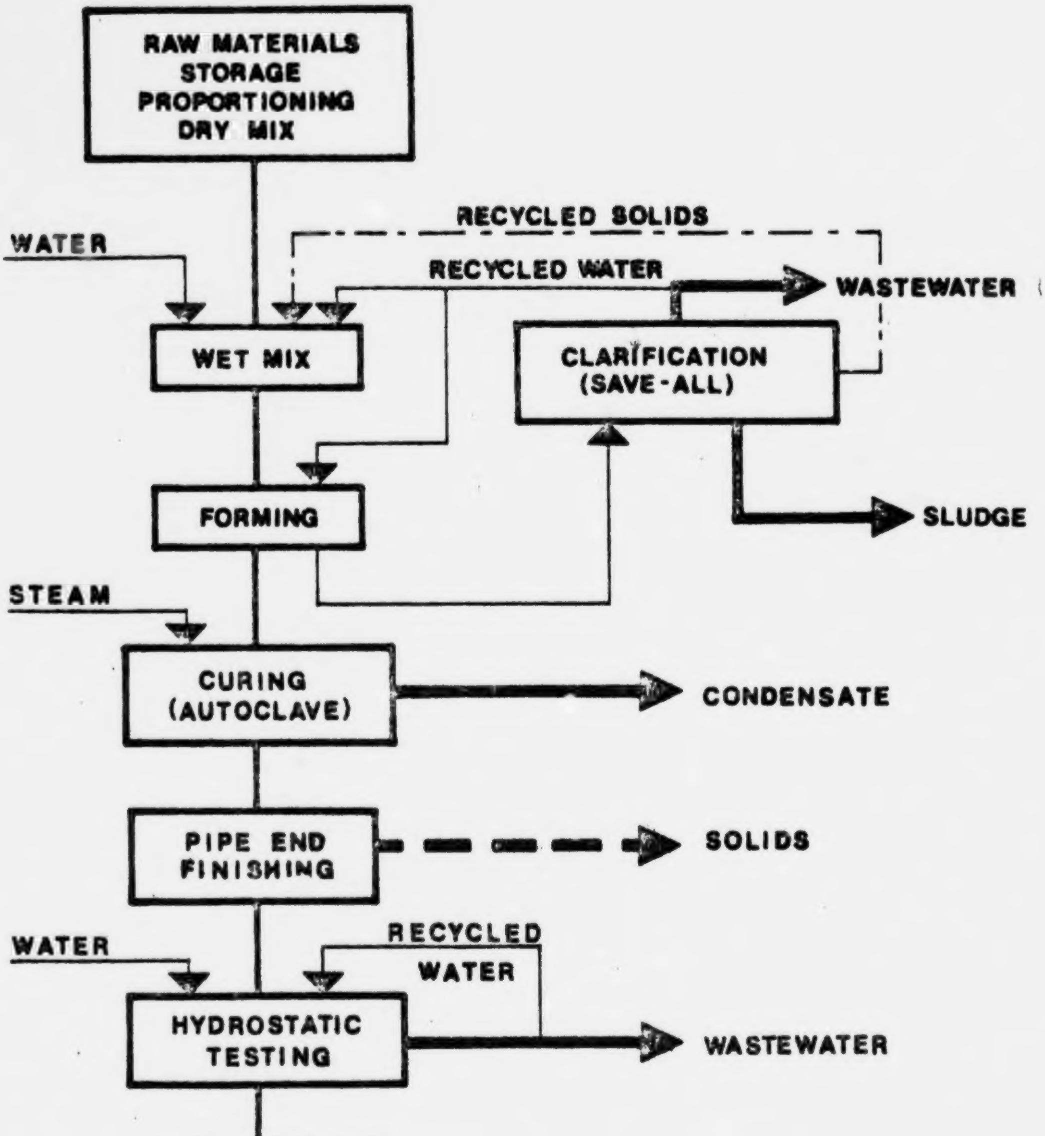
RAW MATERIALS
STORAGE
PROPORTIONING
DRY MIX
WATER
RECYCLED SOLIDS
RECYCLED WATER
WASTEWATER
WET MIX
CLARIFICATION
(SAVE-ALL)
FORMING
SLUDGE
STEAM
CURING
(AUTOCLAVE)
CONDENSATE
PIPE END
FINISHING
SOLIDS
WATER
RECYCLED
WATER
HYDROSTATIC
TESTING
WASTEWATER
FINISHING
STORAGE
CONSUMER

Figure 7.1. Asbestos-Cement Pipe Manufacturing Operations, Wet Mechanical Process (Carton, 1974)

basically the same.

> "After thorough blending of the raw materials, the mixture is transferred to a wet mixer or beater. Underflow solids and water from the save-all are added to form a slurry containing about 97 percent water. After thorough mixing, the slurry is pumped to the cylinder vats for deposition onto one or more horizontal screen cylinders. The circumferential surface of each cylinder is a fine wire mesh screen that allows water to be removed from the underside of the slurry layer picked up by the cylinder. The resulting layer of asbestos-cement material is usually from 0.02 to 0.10 inch in thickness. The layer from each cylinder is transferred to an endless felt conveyor to build up a single mat for further processing. A vacuum box removes additional water from the mat prior to its transfer to mandrel or accumulator roll. This winds the mat into sheet or pipe stock of the desired thickness. Pressure rollers bond the mat to the stock already deposited on the mandrel or roll and remove excess water. Pipe sections are removed from the mandrel, air cured, steam cured in an autoclave, and then machined on each end." (Carton, 1974)

It can be noted that, in general, the method used to make A-C pipe is very similar to the methods to make A-C sheet, asbestos paper, and asbestos millboard.

Wastewaters from the asbestos-cement product manufacture are treated by methods which vary from plant to plant. Treatment can range from no treatment at all to 100% recycle. The most common treatment of wastewaters is sedimentation; some form of sedimentation is applied at nearly all plants in the asbestos industry (Carton, 1974). Sedimentation involves allowing the process wastewaters to settle out their suspended solids or wastes in either a clarifier unit or a specifically constructed pond. The sludge and solid wastes which are settled are usually hauled away to landfills. The sedimentation process can be complimented by pH control and by additions of chemical agents to improve the efficiency and time requirement for sedimentation. Considering the entire asbestos industry, the overall efficiency of sedimentation units, or clarifiers, is estimated to be about 94-96% (Carton, 1974). Neutralization, or pH control, is practiced by 30% of the A-C pipe plants (Carton, 1974). Water discharged from sedimentation is both recycled to the manufacturing process and/or released to surface waters or sewers, depending upon the individual plant. A number of plants are currently recycling all waters.

7.3 Quantities of Asbestos Released to the Environment from Manufacture

Listed below in Table 7.3 are the estimated quantities of asbestos released to the environment from A-C pipe manufacture. The estimates in Table 7.3 are not intended to be considered precise quantities; the data required for precise estimates are simply not available. The estimates are based upon available data and engineering assumptions and are intended only to project a general magnitude of release. These qualifications are also applied to all releases from manufacturing estimated in following sections of this report.

Table 7.3. Estimated Annual Environmental Release of Asbestos from A-C Pipe Manufacture (SRC Estimates)

	Quantity (short tons)	Comment
To Waste, Dump, or Landfill:		
rejected pipe & scrap	10,680	fibers bound in cement matrix
baghouse fines	737	free fibers
process wastewater solids	480	fibers bound in cement matrix
To Water:		
from process wastewater	11-12.5	fibers coated with cement
To Air:		
from baghouse emissions	0.1-2.2	free fibers

In addition to the emission quantities estimated in Table 7.3, a comment has been added to identify the emissions as either free-fibers or fibers bound in a matrix. This is an important consideration. Free-fiber emissions cause a much greater concern due to the inhalation potential with human exposure. Fibers bound in a matrix are generally not susceptible to human exposures unless acted upon by some mechanical force, such as grinding or crushing, or incineration.

The quantitative estimates in Table 7.3 were derived by methods which are discussed below.

7.3.1 Release From Baghouses and Rejected Pipe and Scrap

Harwood and Ase (1977) have estimated that 5-10% of the product material, for asbestos-cement products in general, is dumped as scrap, of which 10% is fine dust from baghouse collection and 90% is coarse scrap from trimmings and breakage and from products which have failed quality assurance testing. In a model plant projection based upon Johns-Manville's A-C pipe plant in Denison, Texas, Harwood and Ase (1977) have determined the following relationships:

(1) daily production of A-C pipe is about 220 short tons for six days per week for 50 weeks per year
(2) product composition is 45% portland cement, 30% quartz silica, and 25% asbestos; dry waste emissions have the same composition
(3) reject pipe and scrap = 14.5 short tons per day
(4) fines collected in baghouse = 1 short ton per day

Based upon a total A-C pipe production of 900,000 tons per year (Table 7.1), the industry-wide total of reject pipe and scrap would be about 59,334 tons and the total fines collected from baghouses would be 4,092 tons. Although Harwood and Ase (1977) have reported an asbestos content of 25%, industry spokesmen believe that an 18% figure is more accurate for the entire industry. Therefore, an 18% asbestos fiber composition assumption of the wastes yields the asbestos release quantities given in Table 7.3.

The main focus of the Harwood and Ase (1977) study was to examine the asbestos emissions from waste piles created by manufacturing plants. Their work was done at Johns-Manville's plant in Denison, Texas. At this particular plant the fines from the baghouse were dumped in the waste area, in a free-fiber state, along with the reject pipe and scraps, and then all of the wastes were crushed together by a bulldozer. A waste pile is apparently a common feature of most asbestos-cement manufacturing plants; additional monitoring of waste piles for asbestos emissions is contained in Harwood and Blaszak (1974). Harwood and Ase (1977) monitored rather sizeable fiber emissions from the Denison plant's waste pile; however, a large degree of these emissions was attributable to the free-fiber state of the baghouse fines; it was assumed that 0.01% of the rejected pipe became airborne during crushing. However, it is not clear that all industry plants dispose of their baghouse fines in this manner. Trosper (1976) notes that there are basically three choices of disposal of asbestos dust collected by a baghouse: (1) one can pelletize the dust that one has collected; (2) one can cast cakes out of it using cement or some sort of a solidifying matrix that encapsulates the material; or (3) one can reprocess the material. In general, the fibers collected by baghouses are too short to be reprocessed back into A-C products because fine fibers add no strength to the cement matrix. Several industrial spokesmen indicated that some baghouse fines are mixed with cement and then disposed in landfills. Therefore, referring to Table 7.3, some of the dumped fines are encapsulated by cement and are not in a free-fiber state.

Harwood and Ase (1977) and Harwood and Blazsnak (1974) have concluded that waste piles of asbestos manufacturing plants pose a potential emission threat to populations within their proximity. However, it is not possible to quantify potential emissions from these waste piles industry-wide because of variations in climate, moisture, and operating procedures. Therefore, no attempt has been made to do so.

Speaking in terms of the overall asbestos industry, and not just the A-C pipe segment, control of atmospheric emissions of asbestos has been made mandatory under Section 112 of the Clean Air Act (Siebert et al., 1976). It is estimated that over 95% of the controls in asbestos manufacturing and fabricating operations are by means of exhaust ventilation (Weaver, 1976). Filtering of these exhausts is commonly done by baghouses with fabric filters. Siebert et al. (1976) have studied the efficiency of asbestos baghouse filters and have concluded, "for all the fabrics and values of the baghouse operating parameters tested, the mass efficiencies of asbestos collection exceeded 99.99%." However, even while obtaining such high efficiencies, Siebert et al. (1976) reported that extremely high numbers of small fibers may still be emitted; typical outlet concentrations of asbestos fibers emitted were found to be on the order of 10^8-10^9 fibers/m^3 (for fibers > 0.06 μm) and 10^5-10^7 fibers/m^3 (for fibers ≥ 1.5 μm).

Air exhaust and ventilation is usually measured in CFM (cubic feet per minute). Assuming a six day work week, a 100 CFM exhaust rating would exhaust about 4.3×10^7 cubic feet per year. Therefore, the following computation can be made which will estimate an average quantity of asbestos emitted from a baghouse filter per year per 100 CFM rating. The monitored emission concentration of 10^8-10^9 fibers/m^3 is averaged as 5×10^8 fibers/m^3; also,

10^3 asbestos fibers have been estimated to equal one nanogram (Bruckman and Rubino, 1975):

$$5\text{x}10^8 \ \frac{\text{fibers}}{\text{m}^3} \text{ X } \frac{1 \text{ m}^3}{35.31 \text{ ft}^3} \text{ X } \frac{10^{-9} \text{ grams}}{10^3 \text{ fibers}} \text{ X } \frac{1 \text{ lb}}{453.6 \text{ grams}} \text{ X } \frac{4.3\text{x}10^7 \text{ ft}^3}{\text{yr}}$$

$$= 1.34 \ \frac{\text{lb asbestos fiber emitted}}{\frac{\text{yr}}{100 \text{ CFM rating}}}$$

The figure calculated above must be considered to be a "worst possible" emission factor. The reason for this is a controversy concerning the use of a conversion factor to convert fiber numbers into weight. Above, we used the Bruckman and Rubino (1975) factor of 10^3 asbestos fibers per nanogram. Other conversion factors have been developed but their validity has been questioned (NIOSH, 1976). NIOSH (1976) states that attempts to formulate such a conversion have generally been unsuccessful because variables are exceptionally large. For example, ambient levels are generally determined using electron microscopy, whereas phase contrast microscopy is used to measure occupational exposures. In addition, techniques used to prepare samples for electron microscope observations may cause alterations in fiber size distributions. In NIOSH's (1976) review of conversion formulations attempted, they noted that all researchers produced large variations in relationships as evidenced by large geometric standard deviations.

The following is a brief review of weight assessment from fiber numbers to produce a conversion factor. Lynch et al. (1970) published results showing that one nanogram of asbestos may be roughly equivalent to 6.7-46.5 fibers > 5 μm, depending upon the industrial operation involved. Nicholson et al. (1975) generated data which showed that one nanogram of asbestos ranged from none detected to 6,570 fibers > 5 μm by phase contrast microscopy. By averaging the data, it was calculated that one nanogram was equivalent to 52 fibers > 5 μm in length. Nicholson (1973) showed one nanogram of amphibole fibers to be equivalent to 604-108,000 amphibole fibers by electron microscopy, with an average of 30,600 fibers/ng. Dement _et al_. (1975) provided additional data for the amphiboles conversion; they calculated that one nanogram was equivalent to 1,200 total fibers by electron microscopy or 400 fibers > 5 μm in length by phase contrast microscopy. Bruckman and Rubino (1975) have suggested a conversion ratio of 20 asbestos fibers > 5 μm in length, as determined by optical microscopy, per nanogram of asbestos. This figure is for chrysotile and is consistent with the results of Lynch _et al_. (1970) and only 2.5 times smaller than the average produced by Nicholson _et al_. (1975). Lynch _et al_. (1970) additionally determined that about 2% of the total number of fibers are observable by optical microscopy as compared to electron microscopy. This gives the derivation of 1,000 fibers per nanogram observable by electron microscopy. This appears to be the best conversion factor available and it is therefore used in this report. It should be noted that use of this conversion factor for determining quantities of asbestos released in process wastewaters resulting from manufacturing gave results which were remarkably consistent with results determined by completely different methods (see Section 7.3.2, 8.3.2).

The problem with using the conversion factor for baghouse emissions is that the fibers which are emitted are extremely small, but the factor was determined by averaging both large and small fibers. Therefore, the emission factor of 1.34 lbs. emitted per 100 CFM rating is probably too high. However, it does give us an opportunity to make some very rough emission estimates.

The amount of asbestos fiber emitted by baghouses, during operations, can now be estimated by two separate methods for A-C pipe manufacturing plants. First, from Table 7.3, about 1,023 tons of asbestos fibers are collected by baghouses industrywide per year. Assuming that each baghouse has an efficiency of 99.99% (Siebert et al., 1976), then an industry total of about 0.1 tons of fibers are emitted per year.

The second method of estimating the asbestos emissions from baghouse operations makes use of the emission factor for each 100 CFM rating which was calculated above. The following assumptions are made: (1) an average A-C pipe plant contains about 10^5 cubic feet of space to be ventilated, and (2) about 15 air changes per hour are made. When the total air volume per year is calculated from these assumptions and then applied to the emission factor of 1.34 lbs. asbestos fibers emitted per year 100 CFM rating, the results indicate that an average A-C pipe plant emits about 336 lbs. of fiber per year from baghouses. Since there are 13 plants (Table 7.2), the industrywide emission would total about 4,368 lbs. or about 2.2 tons. This total is higher than the 0.1 ton estimated by the first method. It should be remembered that the 1.34 lbs. emitted per 100 CFM rating factor is a "worst possible" emission, as explained earlier; therefore, the 2.2 ton estimation may be too high. However, if a baghouse operates at anything less than 99.99% efficiency, then the 0.1 ton estimation could be significantly increased.

7.3.2 Release From Process Wastewaters

The raw water discharge from the typical A-C pipe manufacturing process contains approximately 6.3 lbs. of suspended solids per ton of product produced (Carton, 1974). The suspended solids are comprised of both organic materials and inorganic materials. Organic materials can include grease, tar, oil, fats, various fibers, sawdust, etc., while the inorganic materials can include asbestos, sand, silt, clay, and cement. "The asbestos fiber content of the (suspended) solids is reported to be relatively low, with the bulk of the solids originating as cement, silica, clay, and other raw materials" (Carton, 1974). For A-C pipe production we assumed that the suspended solids are 18% asbestos fiber because, on average, asbestos makes up about 18% of the raw materials by weight (see Section 7.2). We also assumed, for the calculation below, that the clarifiers which settle the suspended solids are about 94% efficient (Carton, 1974). The efficiency of industrial clarifiers, with respect to asbestos particles, is not available. The 94% figure previously quoted relates to gross suspended solids. Asbestos may not behave in the same fashion as gross suspended solids; therefore, the use of the 94% efficiency in the calculation may be questionable. From Table 7.1, about 900 thousand tons of A-C pipe product are annually produced. Therefore:

$$900{,}000\ \frac{\text{ton product}}{\text{yr}} \times 6.3\ \frac{\text{lb solids}}{\text{ton product}} \times \frac{0.18\ \text{lb asbestos}}{1.0\ \text{lb solids}} \times$$

$$.94\ \text{eff.} = 9.6 \times 10^{5}\ \frac{\text{lb asbestos}}{\text{yr}}$$

$$\text{or:}\ \frac{\text{480 tons asbestos settled by clarifiers}}{\text{yr}}$$

In general, most of the suspended solids collected from settling in clarifiers are loaded onto trucks or other transport units and hauled away to landfills;

Capco and Johns-Manville are examples of manufacturers who follow this practice (Stewart *et al.*, 1976). Landfills are usually, but not always, located on company grounds. The asbestos fibers in these solid wastes are covered with cement and can form very hard concretions (Carton, 1974). Stewart *et al.* (1976) noted, in their asbestos fiber concentration analysis of water effluents from A-C systems, that a high percentage of fibers were encrusted with a cementation product. It is therefore probable that the asbestos fibers in this solid clarifier waste are tightly bound in a cement matrix which could make further release of asbestos fibers very difficult, especially when buried in a landfill.

The water effluent from the clarifiers also contains asbestos fiber; the quantity of asbestos released via this source has been estimated by two separate methods. First, the water effluent from the clarifiers in a typical plant contains about 0.38 lb suspended solids per ton of product produced (Carton, 1974). However, four of five pipe manufacturers who were field tested by Stewart *et al.* (1976) had begun recycling this wastewater rather than releasing it. These were some of the larger manufacturers; it is doubtful if a majority of the smaller manufacturers are recycling at this time. There is no current data available to indicate what percentage of the industrywide effluent is recycled. Therefore, we arbitrarily assumed that 60% of the total pipe production is now utilizing water recycling and that the remaining 40% is using standard clarification; using this assumption, about 12.5 tons asbestos per year are released in water effluents from A-C pipe plants:

$$900{,}000\ \frac{\text{ton product}}{\text{yr}} \times 0.38\ \frac{\text{lb solid}}{\text{ton product}} \times 0.18\ \frac{\text{lb asbestos}}{\text{lb solid}} \times 40\%\ \text{release}$$

The second method for estimating asbestos release in water effluents is based upon monitoring data of asbestos concentrations. Lawrence and Zimmerman (1977) found that the asbestos concentration of process wastewater which has undergone sedimentation at an asbestos-cement processing plant is 10^9-10^{10} fibers per liter. The total water effluent discharge from A-C pipe production is estimated at about 12×10^8 gal/yr .

$$\text{(SRC estimate: } 900{,}000\ \frac{\text{ton product}}{\text{yr}} \times 1350\ \frac{\text{gal average*}}{\text{ton product}} = 12 \times 10^8 \text{ gal/yr)}$$

Note that 10^3 asbestos fibers equals one nanogram (Bruckman and Rubino, 1975). Using a 10^{10} fiber per liter concentration, the following computation can be made:

$$10^{10}\ \frac{\text{fibers}}{\text{liter}} \times \frac{10^{-9}\ \text{grams}}{10^3\ \text{fibers}} \times 12 \times 10^8\ \frac{\text{gal discharge}}{\text{yr}} \times 3.785\ \frac{\text{liter}}{\text{gal}}$$

$$\times \frac{1\ \text{ton}}{9 \times 10^5\ \text{grams}} \times 40\%\ \text{release} = 20\ \frac{\text{ton}}{\text{yr}}$$

The same computation using 10^9 fibers per liter yields 2 tons asbestos release via water effluent per year. The average of 20 tons per year and 2 tons per year (11 tons/yr) is in close agreement with the first method which resulted in a calculated value of 12.5 tons per year. These values are dependent upon the arbitrary assumption of a 40% release.

7.4 Asbestos Release from the Use of A-C Pipe

Three studies which have been conducted to determine the levels of asbestos released from the use of A-C pipe in water transport are a Johns-Manville Research Center study (reported in Kuschner et al., 1974), and studies by Hallenbeck et al. (1977), by Buelow et al. (1977), and by Craun et al. (1977). The results of these studies indicate that the amounts of asbestos released during use are small.

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*Carton, 1974

The Johns-Manville Research Center studied two asbestos-cement pipes in two different municipal water systems in order to determine if chrysotile was released. The two pipes, of unspecified ages, were examined over a period of about one year. Paired water samples were taken before and after the water had flowed through the pipes. On average, the flow of water through the two pipes increased the asbestos fiber concentration by 0.074 μg/liter and by 0.004 μg/ liter, respectively. This translates to fiber level increases of 7.4×10^4 fibers/liter and 0.4×10^4 fibers/liter, respectively.

In addition, Johns-Manville examined chrysotile loss from a closed loop system of A-C pipe under laboratory conditions. The results indicated that an average of 21.9×10^9 gallons of water are required to release one gram of fibers.

Hallenbeck et al. (1977) studied fifteen A-C pipes of various ages, lengths, and diameters for possible release of chrysotile asbestos under field conditions. The pipes were located in northeast Illinois. Paired water samples were taken from water before and after it flowed through the pipes. The water samples were analyzed for chrysotile by transmission electron microscopy. Chrysotile was identified on the basis of morphology and electron diffraction pattern. Under the conditions and limitations of this study, no significant release of chrysotile from A-C pipe was observed. On the basis of average fiber counts, eight "after" samples showed a slight increase in chrysotile, six showed a slight decrease, and one group of paired samples was the same. On the basis of average mass data, there were seven increases and eight decreases.

Hallenbeck also notes that many water systems under actual use may have a layer of $CaCO_3$ coating the interior pipe wall, thus preventing actual contact of the water and A-C surface. Hallenbeck hypothesizes that fibers which are already present in the water may break down in transit and thus create the appearance of chrysotile release, in terms of fiber count, from asbestos-cement pipe.

Buelow _et_ _al_. (1977) have conducted, to date, the most complete evaluation of potential asbestos fiber release from A-C pipe use with a field examination of potable water supplies from six different utilities having various water qualities and using A-C pipe. To determine the possible release of asbestos fibers from the pipe walls, samples of water as it entered the pipe and after flowing through the pipe were examined under an electron microscope. The quality of the water of each of the six utilities' water supply was determined by a combination of pH, alkalinity, and calcium hardness, which produced an Aggressive Indices (A.I) in accordance with standards established by the American Water Works Association (AWWA, 1975). The Aggressive Indices are simply a definition of the chemical aggressiveness of the water.

The evaluation of the six water supplies, which covered varying geographical areas of the U.S., produced the following results. Water of a non-aggressive or non-corrosive quality produced little or no increases in fiber levels after transport through A-C pipe. However, significant increases in fiber levels were produced when water of an aggressive nature was transported through A-C pipe. Fiber level increases were monitored in the order of 10^5-10^6 fibers per liter. One increase of 10^7 fibers per liter was noted. Buelow _et_ _al_. (1977) noted that the pH of aggressive water increases during flow through A-C pipe as a result of the water dissolving the cement out of the pipe. The dissolution of the cement causes deterioration of the pipe and the release of asbestos fibers. As the water is exposed to more and more of the pipe, the increase in pH and calcium cause the water to become less aggressive. Specimens of A-C pipe cut from aggressive water supplies showed the above described patterns of attack on the pipe.

The deterioration of A-C pipe from the most aggressive water system analyzed by Buelow (Pensacola, Fla.) resulted in clogged water meters, problems at coin-operated laundries, and collection of visible fibers in kitchen faucet strainers.

Craun *et al*. (1977) have examined potable water in Connecticut for asbestos concentrations in water flowing through A-C pipe. They were attempting to investigate the use of A-C pipe for public water supplies and the incidence of gastrointestinal cancer. Based upon their sampling results, it was concluded that the population served by public water systems not using A-C pipe was not exposed to significant amounts of naturally occurring asbestos in water. As for the population utilizing A-C pipe for water supplies, Craun *et al*. (1977) have initially reported that the use of A-C pipe probably has not been responsible for excess gastrointestinal cancers. Nineteen samples were analyzed from distribution systems after water had passed through various lengths of A-C pipe. Chrysotile fiber counts ranged from below detectable limits (10,000 fibers/liters) to 700,000 fibers/liter. Some amphiboles were detected; concentrations were below 50,000 fibers/liter.

Several points should be made with regard to the above studies. First, the amount of data which has been generated is actually quite small. Only a very small percentage of the A-C pipe currently in service has been monitored for potential fiber release. Also, if chemical aggressiveness is the major factor contributing to fiber release from A-C pipe use, then it is difficult to estimate what percentage of water supply systems may potentially be undergoing deterioration because there is currently no data available by which to make such estimations. In addition, only the studies of Buelow et al. (1977) and Craun et al. (1977) quantitatively monitored for amphibole varieties of asbestos; Johns-Manville and Hallenbeck et al. (1977) were concerned only with chyrsotile. Also, there has been no monitoring of A-C sewer pipe use for potential fiber release. It would seem possible that potentially corrosive or aggressive liquids may undergo disposal through A-C pipes. Some monitoring of A-C sewer pipe wastes for fiber releases appears to be very desirable.

However, from the results of the available studies, it may be assumed that use of asbestos-cement pipe for water transport does not seem to contribute any large amounts of asbestos fibers into the general environment. When compared to the quantitative asbestos release from the use of brake linings, or asbestos release from milling, mining, and manufacturing, the use of A-C pipe probably contributes very little into the total environmental release.

What is more important, however, is the fact that A-C pipe is used for potable water supplies. Considering this application, small releases of asbestos fiber may very well be important.

A number of investigators have identified and measured asbestos fibers in drinking water supplies (Cooper and Murchio, 1974; Kay, 1974; Cook et al., 1974; Cunningham and Pontefract, 1971 and 1973; Stewart et al., 1976; McMillan et al., 1977; Flickinger and Standridge, 1976). However, much of the data generated by these investigators was samplings from source supplies and did not include any use of A-C pipe. Levels commonly found in drinking water supplies ranged from 10^5 to 10^6 fibers per liter. These levels are much higher than the average increases in fiber content suggested by the studies of Johns-Manville in their testing of A-C pipe but are in line with fiber level increases determined by Buelow _et al_. (1977) for very aggressive water. "Pick-up of asbestos in water that flows through asbestos-cement pipe is very small, and, frequently, many source waters contain more asbestos fiber than does water that flows from asbestos-cement pipes" (Olson, 1974).

Two related points to consider are the following: (1) chrysotile asbestos was found in Chicago rainwater at a level of 10^5 to 10^6 fibers per liter (Hallenbeck _et al_., 1977), and (2) levels of 10^6 fibers per liter were detected in Ottawa melted snow samples (Cunningham and Pontefract, 1971).

The consideration of a potential health problem from drinking water containing these levels of asbestos fibers is beyond the scope of this report.

Under certain conditions, it may be possible for asbestos fibers in water to become airborne. For example, certain types of commercial and residential humidifiers operate on the principle of atomizing water into forced heating air. If it is assumed that the water supply to this type of humidifier contains asbestos, it may be possible that the fibers are emitted into room enclosures through heating ducts. The following hypothetical calculation attempts to estimate the levels of asbestos which may be added to indoor air as a result of humidifiers using water containing asbestos. As noted above, levels of asbestos monitored in water supplies have ranged from 10^5 to as high as 10^7 fibers/liter; also, aggressive waters can cause A-C pipe to raise asbestos levels to the same ranges. For the purposes of this calculation, it is assumed that the asbestos water concentration is 10^7 fibers/liter. It is assumed that an atomizing humidifier is being used by a homeowner, whose house contains roughly 400 m^3 (14,000 ft^3), and is connected to the central heating system. The humidifier injects one liter of water, containing 10^7 fibers/liter, into the heating system each hour. Therefore, during the course of one day, the asbestos air concentration of the house could theoretically be raised:

$$\frac{24 \text{ hr} \times 10^7 \text{ fibers/hr}}{400 \text{ m}^3} = 6 \times 10^5 \text{ fibers/m}^3 = 0.6 \text{ fibers/cm}^3 = 600 \text{ ng/m}^3$$

This calculation is completely theoretical and is not based upon any indoor air monitoring. Additionally, it does not consider any recycle ventilation through air filters. It may, however, deserve some consideration.

7.5 Alternatives to A-C Pipe

A-C pipe is principally used for water distribution and sewer systems. In the first application it competes primarily with PVC, cast iron, and steel pipe; in the second application it competes primarily with vitrified clay, concrete, cast iron, and PVC pipe. Speaking in general terms, asbestos-cement is one of the least costly pipe materials. Only locally produced clay and concrete pipe is less expensive in all size ranges. Cast iron and steel are appreciably more expensive than A-C pipe in all size ranges. In general, A-C pipe has a price advantage of about 10% over PVC pipe in most sizes (Lawless, 1977). However, the price advantage can shift to PVC in some larger size applications.

The choice of pipe material is commonly determined by its specific application and its cost effectiveness in this application. For example, the various types of sewer pipe have different flow characteristics and corrosion resistance. The elevation gradient and type of fluid used in the sewer can determine which pipe material will be least costly for that application. One type of pipe may require a slightly larger diameter to handle the required flow, and thereby becomes more costly to install.

A-C pipe is primarily used in water supply where the competitive pipe materials are PVC, cast iron, and steel. When installed in underground applications, A-C has an advantage over cast iron and steel in that it rarely corrodes from the outside. As a matter of fact, cement products are commonly known to become structurally stronger after being left underground for a period of time (Lawless, 1977). On the other hand, cast iron and steel begin to corrode from the moment they are placed in the ground. They rust, scale, and need cathodic protection. However, cast iron and steel are very old and proven water supply materials and thereby command a healthy percentage of the water supply market.

The new-comer to the market is PVC pipe. For water supply purposes, PVC is estimated to have penetrated into 20-30% of the total market (Frey, 1976). PVC is also penetrating into all other pipe market applications. Future growth in the production of PVC pipe has been estimated to be as high as 15-20% per year (Frey, 1976). One application in which PVC is replacing A-C pipe is in large, rural water mains (Gresham, 1977). In many of these rural applications the pipe is not required to meet fire-code or AWWA strength standards. This enables a PVC pipe to be produced with a thinner wall and, thereby, a cheaper cost than can be accomplished with a corresponding A-C pipe.

Asbestos-cement pipe and PVC pipe are strong market competitors. What is interesting is the fact that the Johns-Manville Corp. and Certain-Teed Corp. are two of the largest manufacturers of both products. From Table 7.2 it can be seen that Johns-Manville and Certain-Teed control a very sizeable portion of the A-C pipe market. Frey (1976) lists Johns-Manville and Certain-Teed as two of the three largest producers of PVC pipe, each having extrusion capacities of 200-300 million lbs. per year; Johns-Manville is listed as the largest in the U.S. Johns-Manville has 12 extrusion plants, while Certain-Teed has six. In 1975, an estimated 1,020 million lbs. of PVC were consumed in pipe production.

PVC has long been resisted by plumbers' unions and cast iron pipe interests (Frey, 1976). However, market fundamentals, such as cost, demand, and satisfactory performance, favor continued strong expansion of PVC pipe. "According to industry observers, leading in the expected continued expansion of PVC pipe and conduit applications will be low-pressure pipe, particularly large diameter water pipe (12 inches and larger), and sewer pipe. Other end uses also expected to continue to grow include telephone conduit and residential hot-water pipe made from post-chlorinated PVC" (Frey, 1976).

Disregarding cost, A-C pipe appears to be completely replaceable by alternative pipe materials.

7.5.1 Fiber Replacement in Cement

Work has been done by many companies to find a fiber replacement for the asbestos fiber in A-C pipe. To date, no fiber has been found which can duplicate or exceed asbestos's strength, resistance, and other characteristics when applied to a cement matrix (Jackson, 1977; Lawless, 1977). Types of fibers experimented with have included fiberglas, glass, metallic, graphite, and various natural fibers.

Fiberglas fibers have proven unuseable in that fiberglas is not alkali-resistant. In an alkali-type matrix such as cement, the fibers are simply dissolved away in time (Lawless, 1977). Relatively new alkali-resistant glass fibers are now being experimented with and are showing potential promise as an asbestos fiber replacement in cement. However, within the cost framework of asbestos fibers and A-C pipe, there is no fiber which can replace asbestos at this time (Jackson, 1977).

8.0 ASBESTOS-CEMENT SHEET

Asbestos-cement sheet is a flat or corrugated cement product, using asbestos fiber as a reinforcing agent, that is widely used in construction applications such as roofing and siding for both industrial and residential buildings. It is also used in the manufacture of heaters, boilers, vaults and safes, electrical equipment mounting panels, welding shields, and many other applications requiring a non-combustible or heat-resistant sheet (Daly *et al.*, 1976).

The corrugated sheet is used primarily in industrial applications as roofing or siding or in warehouse construction for phosphate fertilizers or other corrosives. The flat sheet has a variety of construction uses. Currently, one of its larger uses is as a substrate for curtain walls in building construction; in this application, the building contractor applies an epoxy-type finish to the sheet before attaching it to the building exterior. Asbestos-cement sheet is used in its various applications primarily due to its resistance to corrosion, mildew, etc. as well as its fire code rating. It is not intended to be used as weather insulation (Breiner, 1977).

8.1 Use Quantities, Shipment Values & Industrial Firms

U.S. demand for asbestos in A-C sheet products has ranged from 23 to 95 thousand short tons annually during the 1967-1976 period; in 1976, about 23 thousand tons of asbestos were consumed in A-C sheet (Tables 4.9 and 4.10, p. 46). According to the 1976 figures, about 3.1% of the total U.S. market for asbestos was consumed in the production of A-C sheet; this 3.1% figure is down sharply from the 11.2% and 7.2% market shares in 1974 and 1975, respectively. A large portion of the apparent decrease from 1974 to 1976 is attributable to a change in reporting definitions; that is, that portion of A-C sheet produced for roofing purposes is listed, in 1976, under roofing and not under A-C sheet.

In recent years, the growth of the market for A-C sheet in the U.S. has lagged behind that of the construction industry in general, amounting to only a few percent per year (Igwe, 1974). At this time, the market for corrugated sheet is stable and is projected to remain that way, however, the flat sheet market has fallen somewhat and small decreases in the future are foreseen (Breiner, 1977). A combination of competitive pressures from alternative products and concern for exposure to asbestos fibers by contractors are the main reasons for the slight market decreases.

Table 8.1 lists the shipment values of A-C sheet. Unfortunately, quantities such as poundages are not given by the Census Bureau. Igwe (1974) reports that about 400,000 tons of A-C sheet were produced in 1973. However, based upon the classification system used in 1976, approximately 125,000 tons of A-C sheet were produced in 1976 for purposes other than roofing (SRC estimate). The A-C sheet made for roofing is considered in section 9.0 (Asbestos Roofing); this is especially important to note when considering environmental releases.

Table 8.2 lists the major manufacturers of A-C sheet along with their respective locations. Data for recent sales by the individual locations is not available; most of the locations have diversified product lines.

8.2 Manufacturing Process Technology

Flow diagrams and brief descriptions of processes used to produce A-C sheet are included in section 9.2, and will therefore not be detailed here. The manufacturing process for A-C sheet is quite similar to the process used to produce A-C pipe, especially in terms of environmental releases and their treatment. This permits an identical approach to estimating quantities of asbestos release as was described for A-C pipe.

Table 8.1 Shipment Values of Asbestos-Cement Sheets
(U.S. Bureau of the Census, 1972 Census of Manufacturers)

		Total Product Shipments, including interplant transfers (millions of dollars)	
SIC Product Code	Product	1972	1967
32927 41	Flat sheets and wallboard	20.7	15.2
32927 51	Corrugated sheets	5*	3.5

* SRC estimate.

Table 8.2 Major Manufacturers of A-C Sheet (Carton, 1974 modified by several industrial sources)

Manufacturer	Location
Johns-Manville	Waukegan, Ill. Nashua, N.H.
GAF Corp.	Mobile, Ala. St. Louis, Mo. South Bound Brook, N.J.
National Gypsum	New Orleans, La.
Celotex Corp.	Cincinnati. Oh.
Nicolet Ind.	Ambler, Pa.

Nearly all of the asbestos presently used in A-C sheet is chrysotile; a very small amount of amosite and anthophyllite is also used (Table 4.10, p. 46). The asbestos content of the A-C sheet product can vary depending upon intended use. A-C sheet products manufactured by Johns-Manville contain 30-40% asbestos; therefore, it will be assumed that A-C sheet contains an average content of 35% asbestos. This figure is used in estimating releases from process wastewaters.

8.3 Quantities of Asbestos Released to the Environment from Manufacture

Listed below in Table 8.3 are the estimated quantities of asbestos released to the environment from A-C sheet manufacture. The estimates in Table 8.3 are intended to estimate a general magnitude of release only.

Table 8.3 Estimated Annual Environmental Releases of Asbestos from A-C Sheet Manufacture (SRC Estimates)

	Quantity (short tons)	Comment
To Waste Dump or Landfill:		
rejected sheet & scrap	1525	fibers bound in cement matrix
baghouse fines	105	free-fibers
process wastewater solids	74	fibers bound in cement matrix
To Water:		
from process wastewater	1.9	fibers coated with cement
To Air:		
from baghouse emissions	0.01 - 1.5	free-fibers

The estimates in Table 8.3 were derived by methods which are explained in the following subsections.

8.3.1 Release From Baghouses and Rejected Sheet and Scrap

As detailed in section 7.3.1, Harwood and Ase (1977) have estimated that 5-10% of the product material, for A-C products in general, is dumped as scrap, of which 10% is fine dust from baghouse collection and 90% is coarse scrap from trimmings and breakage and from products which have failed quality assurance testing. If it is assumed that the A-C sheet product is about 35% asbestos fibers, then about 66,000 tons of A-C sheet product were produced in 1976 based upon the asbestos consumption of 23,000 tons listed in Table 4.9 (p. 46). As mentioned earlier, this is the A-C sheet production for purposes other than roofing. Approximately an equal amount of sheet was produced for roofing; therefore, if the estimates in Table 8.3 are doubled, then the total releases from all A-C sheet manufacture are derived.

Using the Harwood and Ase (1977) relationships detailed in section 7.3.1, we can calculate the releases from rejected sheet and scrap and baghouse fines as shown in Table 8.3.

The baghouse emissions can be estimated by using the Siebert et al. (1976) figure of 99.99% efficiency of baghouses to yield an estimate of 0.01 tons per year. However, using the factor of 1.34 lb. asbestos fibers emitted per year per 100 CFM rating and assumptions of a plant volume of 10^5 cubic feet and 15 air changes per hour, as detailed in section 7.3.1, it can be calculated that about 1.5 tons of fibers are emitted annually by 8 plants. The discrepancy between the two estimates is large. As mentioned earlier in section 7.3.1, the 1.34 lb. emission factor is a worst possible estimate; therefore, the result of 1.5 tons of fiber emission may be on the high side. In addition, it must be remembered that most A-C sheet production takes place in multi-asbestos product plants which feed a common baghouse, so estimates are only partial to total emissions.

8.3.2 Release From Process Wastewaters

The raw water discharge from a typical manufacturing process contains about 13 lbs. of suspended solids per ton of product produced (Carton, 1974). For A-C sheet production we assumed that the suspended solids are approximately 18% asbestos fiber, because roughly 18% of the raw material composition is asbestos by weight. We also assumed that the clarifiers which settle the suspended solids are 96% efficient (Carton, 1974), and that about 125,000 tons of A-C sheet are annually produced. Therefore:

$$66{,}000\ \frac{\text{tons product}}{\text{year}} \times 13\ \frac{\text{lb. solids}}{\text{ton product}} \times 0.18\ \frac{\text{lb. asbestos}}{\text{lb. solid}} \times .96\ \text{eff.} =$$

$$1.48 \times 10^5\ \frac{\text{lb asbestos}}{\text{year}}\ \ \underline{\text{OR}}\ \ \frac{\text{74 tons asbestos settled by clarifiers}}{\text{year}}$$

Clarifier efficiency, with respect to asbestos particles only, has never been determined. The 96% efficiency factor above relates to gross solids. Settling characteristics for asbestos may differ and the use of the 96% figure may be questionable. It is used for lack of a better figure. In general, the solids collected from settling in clarifiers are disposed of in landfills. As was the case for A-C pipe, the asbestos fibers are covered with cement and become very solid concretions.

The water which is discharged from the clarifiers also contains asbestos fiber; the quantity of asbestos released via this source has been estimated by two separate methods. First, the water effluent from the clarifiers in a typical plant contains about 0.45 lb. suspended solids per ton of product produced (Carton, 1974). However, four of five A-C sheet producers field tested by Stewart et al., (1976) had achieved varying degrees of recycling of the process wastewater. There is no current data available to indicate what percentage of the industry-wide effluent is recycled. Therefore, we assumed that about 30% of the total sheet production is now utilizing water recycling and that the remaining 70% is utilizing standard clarification. Using these assumptions, about 1.9 tons of asbestos per year are released in water effluents from A-C sheet plants

$$66{,}000\ \frac{\text{ton product}}{\text{year}} \times 0.45\ \frac{\text{lb. solids}}{\text{ton pdt.}} \times 0.18\ \frac{\text{lb. asbestos}}{\text{lb. solids}} \times 70\%\ \text{release}\ .$$

The second method for estimating asbestos release in water effluents is based upon monitoring data of asbestos concentrations. Lawrence and Zimmerman (1977) found that the asbestos concentration of process wastewater which has undergone sedimentation at an asbestos-cement processing plant is 10^9 - 10^{10} fibers per liter. The total water effluent discharge from A-C sheet production is estimated to be 1.19×10^8 gal/yr (SRC estimate:

$$66{,}000\ \frac{\text{ton product}}{\text{year}} \times 1800^{*}\ \frac{\text{gal discharge}}{\text{ton product}}).$$

Using a 10^{10} fiber per liter concentration, the following computation can be made:

$$10^{10}\ \frac{\text{fibers}}{\text{liter}} \times \frac{10^{-9\,**}\ \text{grams}}{10^{3}\ \text{fibers}} \times 1.19 \times 10^{8}\ \frac{\text{gal effluent}}{\text{year}} \times 3.785\ \frac{\text{liter}}{\text{gal}}$$

$$\times \frac{1\ \text{ton}}{9 \times 10^{5}\ \text{grams}} \times 70\%\ \text{release} \cong 3.5\ \frac{\text{tons}}{\text{year}}$$

A similar calculation using 10^9 fibers/liters yields about .35 ton asbestos release via water effluent per year. The average of 3.5 tons/yr and .35 ton/yr (1.95 tons/yr) is in close agreement with the first method which resulted in a calculated value of 1.9 tons/yr. These values are dependent upon the assumption of a 70% release.

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[*] Carton (1974)

[**] See section 7.3.1 for discussion of this conversion factor.

8.4 Asbestos Release from Use of A-C Sheet

In the United States, asbestos-cement sheets are used principally for industrial buildings (particularly fertilizer plants and other applications where corrosion is a problem), warehouses, and in similar cost-sensitive markets. It is also used to a limited degree as a siding in the residential market (Igwe, 1974).

The potential release of asbestos fibers from A-C sheet used in the roofing industry is discussed in section 9.4. There it was estimated that the greatest potential for release of fibers was involved with the effects of weather. Similar inferences can be drawn for A-C sheet siding which is exposed to the weather. However, it should be pointed out that there is no available monitoring data by which firm predictions can be made to estimate release quantities from weathering or corrosive effects.

It would seem quite possible that A-C sheet which is not exposed to weathering effects, corrosion, or damaging mechanical forces would release virtually no fibers because the fibers are tightly bound in the cement matrix. Installation of A-C sheet is one mechanical force which may permit release of fibers; demolition of buildings containing A-C sheet is another.

Installation of A-C products may require some sort of field fabrication, such as sawing, trimming, drilling, or grinding, which would release asbestos fibers. However, such fabrication to meet customer specifications is usually done by central fabricating shops (EPA, 1974). The flat asbestos sheets used in homes, barns, or other inexpensive construction are usually installed with fasteners or nails and require little drilling. The EPA (1974) found that the asbestos-cement products that were field-fabricated were usually cut with knives or saws equipped with dust-collection devices, and holes were drilled with drills equipped with dust-collection devices. Accordingly, the EPA (1974) determined that the field fabrication of asbestos products, other than insulating (friable) products, is not a major source of asbestos emissions to the air.

The amount of asbestos-containing dust generated by central shops that fabricate asbestos-cement building products was estimated to be about 200 lbs./week (EPA, 1974). This is an annual rate of 10,400 lbs.; if we assume an asbestos content of 18%, then slightly less than one ton of asbestos fibers is annually generated by these fabrication shops. It is assumed that disposal of these wastes is to dumps or landfills.

The life-expectancy of an A-C sheet product is probably in the range of 15 to 25 years. After this time it will be replaced with a new material. If it is assumed that about 75% of the annual production is for replacement-type purposes, then perhaps 187,000 tons of A-C sheet products are replaced each year containing about 34,000 tons of asbestos. This includes A-C sheet for both roofing and other uses and does not consider any weathering effects. Effects of weather are discussed in section 9.4. It can be further assumed that most of the worn-out or replaced sheet is disposed of in waste dumps or landfills.

8.5 Alternative Products to A-C Sheet

Asbestos-cement sheet refers to a broad family of corrugated and flat board products used in the construction industry for roofing and siding. It competes principally with masonry, galvanized steel, aluminum sheet, plastics, wood and asphalt (Breiner, 1977; Igwe, 1974). A-C sheet is generally more expensive than corrugated steel, competitive with aluminum sheets, and less expensive than conventional concrete blocks and built-up roofing.

One of the main selling advantages of A-C sheet, especially in industrial applications, is its resistance to rot, corrosion, and mildewing (Breiner, 1977). Another advantage is, of course, its fire resistance. However, there is virtually no application in which A-C sheet could not be substituted for by current market alternatives, although the cost may be somewhat higher if alternatives are used.

Replacement for the asbestos fibers, in the A-C sheet products, by some alternative fiber or filler, has been and is being attempted by the major manufacturers. These potential alternatives include fiberglas, glass, carbon fibers, and various natural, synthetic, and mineral fibers. None of these potential alternatives are as good as asbestos in overall characteristics and, additionally, many of the alternatives are more costly. Considering these factors there is no market for an alternative A-C sheet product utilizing fibers other than asbestos.

Cost comparisons between A-C sheet and its competitive products, such as aluminum sheet, steel, etc., have not been included because of the many varieties and thicknesses of materials which are available. A cost comparison would be meaningful only for specific applications.

9.0 ASBESTOS IN THE ROOFING INDUSTRY

The roofing industry consumed approximately one-third the total asbestos fiber consumed in the U.S. in 1976. The quantity, 253,000 tons as now classified, is the largest single use for asbestos (Table 4.9, p. 46).

By the former U.S. Bureau of Mines classification the annual use had been steady near 80,000 tons since 1967 (Clifton, 1974, 1976). The dramatic increase in the 1976 figure is not attributable, however, to a big rise in the asbestos roofing market, but rather to a probable change in reporting classification. Industry spokesmen indicate that the asbestos roofing market is undergoing static growth with foreseeable small decreases and that the large 1976 consumption figure probably includes all asbestos paper, A-C sheet, and asbestos coatings used by the roofing industry. Corresponding decreases in the consumption figures for paper, sheets, and coatings are noted (Table 4.9, p. 46), although not in sufficient quantities to make up the 253 thousand ton figure. It should be noted that in a survey of the asbestos industry, Daly *et al*. (1976) calculated that about 38% of the total asbestos consumption is incorporated in asbestos paper; based on a total consumption of 725,000 tons in 1976, this would amount to 276,000 tons. Since most of the asbestos roofing products produced involve coating asbestos paper with asphalt, etc., the 1976 Bureau of Mines' figure for asbestos consumption in the roofing industry (253,000 tons) may reflect close agreement with the Daly survey. Therefore, we feel that the 1976 figures published by the Bureau of the Mines are probably accurate figures, and, therefore, these figures are used throughout this report in estimating fiber releases. Igwe (1974) estimates that asbestos roofing makes up about 2% of the total roofing industry.

Roofing products being exposed continuously to weather deteriorate slowly, and their resistance to atmospheric conditions is reduced. The material must be eventually replaced and scrapped. Asbestos fiber may thereby be released during these wear and replacement stages, finally reaching the environment in the scrap, in landfills or trash dumps, in water run off from rain and snow, or to some lesser extent as airborne dust. In addition, asbestos fiber can potentially be lost to the environment in fabricating the fiber into the roofing products.

Section 9 will cover specifically these losses of roofing asbestos fiber to the environment and provide approximations of the quantities released.

9.1 Asbestos Roofing Products

The principal roofing products containing asbestos as an essential ingredient are asphalt roofing felt and papers, asbestos-cement roofing sheet and shingles, and asbestos-asphalt paints, coatings, and sealants. All are well established products that have been made since the early 1900's and before.

The asbestos fiber used in roofing products is essentially chrysotile, with about 99% as the finest grade 7 milled mineral (Clifton, 1976). Approximately 85% of the milled product was imported from Canada, as based on the total U.S. consumption. Two mines in the eastern U.S. and four in California and Arizona produced the balance (section 5.1).

Table 9.1 lists manufacturers and locations of asbestos roofing products. The plant at Savannah makes only roofing. All others are multi-asbestos product operations.

Asbestos is added to roofing materials to improve and stabilize strength, to increase resistance to corrosion and rot, as well as to give

Table 9.1 Major U.S. Manufacturers of Asbestos Roofing (Carton, 1974; Igwe, 1974)

Manufacturer	Location
Johns-Manville	Waukegan, Ill. Marrero, La. Manville, N.J. Fort Worth, Tex. Savannah, Ga. Los Angeles, Cal.
GAF Corp.	Millis, Mass. South Bound Brook, N.J.
Celotex Corp. (Jim Walter Corp.)	Linden, N.J. Cincinnati, Ohio Houston, Tex. Memphis, Tenn.

insulating and fire resisting advantages. The high tensile strength of the fine asbestos fiber reinforces the asphalt and cement matrices. The dimensions of the product are maintained and the disintegration of alternative organic reinforcement avoided (Daly *et al.*, 1976).

The available shipping values and quantities of asbestos roofing materials are given in Table 9.2. It is estimated that the 1977 value of products listed in Table 9.2 would be about $70 million (SRC estimate). This represents a sales value of approximately $250 per ton of asbestos contained in the roofing products.

It is judged that since there has been no significant change in recent total consumption of asbestos roofing materials that the relations presented in Table 9.2 are close approximations to current consumption.

9.2 Manufacturing Technology

Asbestos roofing products are made by three major processes. First, the asbestos paper used for the asbestos asphalt roofing felt and paper is made by the usual paper making process. Second, this asbestos paper is impregnated with asphalt by dipping and coating procedures. Third, asbestos-cement flat, corrugated sheet and shingles are made by similar methods as used in asbestos-cement pipe production. Bituminous roofing paint and coating products are made simply by batch mixing asbestos fiber into mastic mixtures.

Dry milled asbestos used for the above processes is received in paper bags which are dumped by manual or semi-manual means into storage facilities or directly into preparatory mixing equipment. Extreme care is required to minimize dust that these operations produce. Hoods and vacuum ventillating systems are required.

Table 9.2 Shipment Values and Quantities of Asbestos Roofing Materials
(U.S. Bureau of the Census, 1972)

SIC Product Code	Product	Total Product Shipments, including interplant transfers			
		1972		1967	
		Quantity (million sq.)	Value ($ million)	Quantity (million sq.)	Value ($ million)
32924 --	Asbestos Cement Shingles & Clapboard				
32924 11	Siding Shingles & Clapboard	1.3	20.8	1.9	24.0
32924 51	Roofing Shingles				
32924 00	A-C Shingles & Clapboard, n.s.k.	--	--		
--	Asbestos Felts:				
32927 81	Roofing, asphalt or tar saturated	7.5*	23.2	--	11.2

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* SRC Estimation calculated by approximation from Value and current (1977) price of $20 per 4 square roll with 50% inflation allowance.

The asbestos paper is made by essentially the same process as used for cellulosic papers. The fiber is pulped with water into a 1-3% slurry. Dry mixing of the fiber and additives may precede the wet pulping. The stock is fed to either a Fourdrinier paper machine or to a multicylinder type machine (Whitney et al., 1967; Carton, 1974). In both machines, paper forms on screen surfaces as the pulp is drawn through. The wet mat is conveyed to steam heated drying cylinders and rolls. After drying, the paper is cut into sheets and collected on rolls. The excess water after fiber removal is recirculated to the pulping step, except for a purge stream that is withdrawn for purification or waste. The purge is the major effluent.

The above felt or paper is then saturated with asphalt or coal tar in a series of steps as shown in Figure 9-1. The first step is the "dry looper" (Berry, 1968) from which the felt is fed to the succeeding steps. In the first, the felt passes through a saturating tank containing melted asphalt at 450-500°F. Next, it is passed to the "wet looper" where the excess asphalt drains off as the saturated sheet cools. The felt is then coated with asphalt at 350-400°F. Minerals may also be added to the surface. The felt is next cooled to 225-275°F on water coated rolls and finally to 100°F by direct water sprays in the "finish looper". The product is finally finished into rolls on a mandrel, cut and trimmed, and wrapped for shipment.

The cooling water may be circulated through a cooling pond or tower or wasted.

For built-up roof felt, the paper is not coated. The felt for this case is field coated by mopping hot asphalt or pitch onto the felt as it is laid in plies at the site. Coated or prepared roofing paper is simply laid in

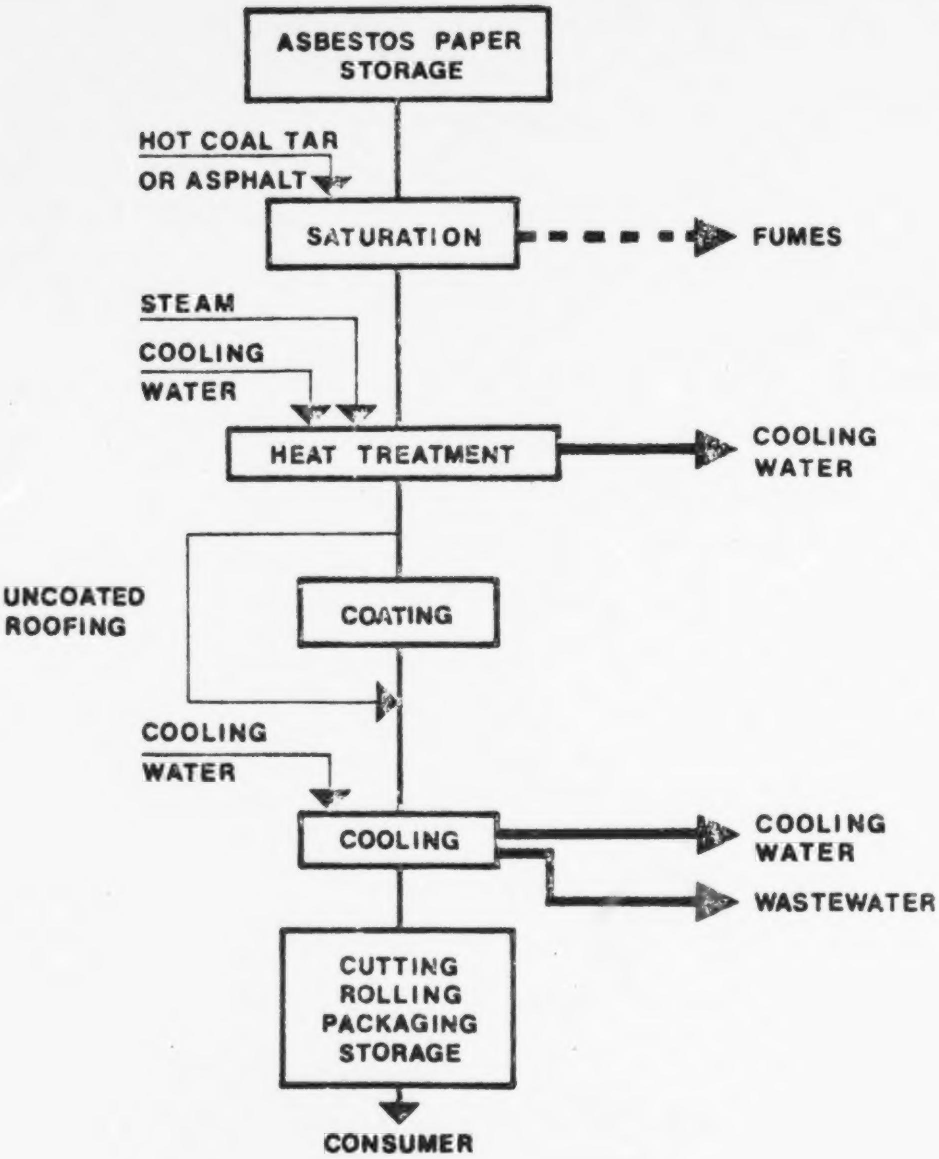

ASBESTOS PAPER STORAGE
HOT COAL TAR OR ASPHALT
SATURATION
FUMES
STEAM
COOLING WATER
HEAT TREATMENT
COOLING WATER
UNCOATED ROOFING
COATING
COOLING WATER
COOLING
COOLING WATER
WASTEWATER
CUTTING ROLLING PACKAGING STORAGE
CONSUMER

Figure 9.1. Asbestos Roofing Manufacturing Operations (Carton, 1974)

plies and cemented together by cold adhesives (Berry, 1968). The amount of material which may be friable before pitching is not available, but is judged to be small.

Asbestos-cement sheet and shingles are made by either a dry process or a wet mechanical process. In the dry process, a dry mixture of fiber, cement, and additives is distributed uniformly onto a flat conveyor belt, sprayed with water, and compressed by steel rolls to required thickness (Figure 9-2). The moving sheet is cut into desired sizes or into shingles and finally steam cured in autoclaves. Water that is used to clean the forming equipment is normally collected for clarification and either recirculated or wasted. The settled solid material from the clarifiers is recycled or wasted in dumps or landfills (Carton, 1974).

In the wet process, Figure 9-3, the asbestos fiber is blended with cement and additives and mixed with water. The mix is pressed to form the product, then air or steam cured, and finally finished into sheets, up to 0.10" thick. The wet mechanical process, Figure 9-4, is similar to the asbestos cement pipe operation, Figure 7-1. The water from the forming step is clarified and recycled similarly, with the same sludge and wastewater disposal requirements.

The production of roof coatings, sealants, paints, and undercoatings consists of mixing asbestos and other additives into an asphalt base (Daly _et al._, 1976). Solvents are added to reduce the viscosity - and especially for spray applications and emulsions. The process is batch. The asbestos fiber is added to the asphalt mastic mix and dispersed evenly, thereby encasing the fibers with the asphalt. The mix is pumped to a container filling station.

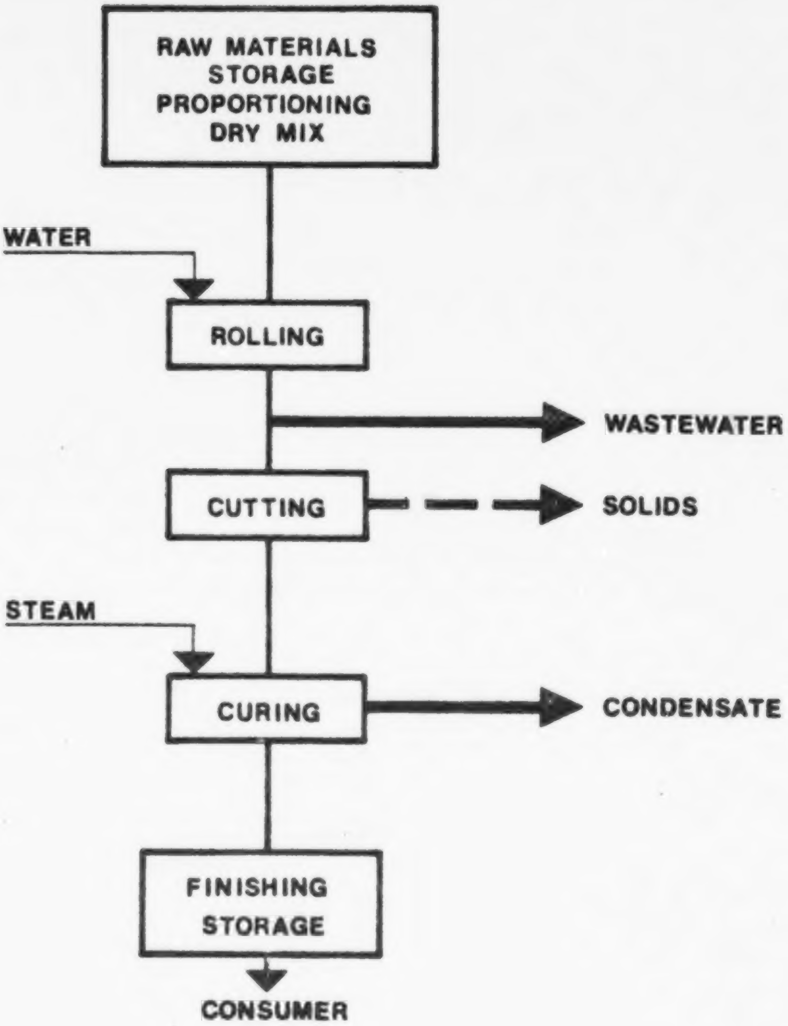

RAW MATERIALS
STORAGE
PROPORTIONING
DRY MIX
WATER
ROLLING
WASTEWATER
CUTTING
SOLIDS
STEAM
CURING
CONDENSATE
FINISHING
STORAGE
CONSUMER

Figure 9.2. Asbestos-Cement Sheet Manufacturing Operations, Dry Process (Carton, 1974)

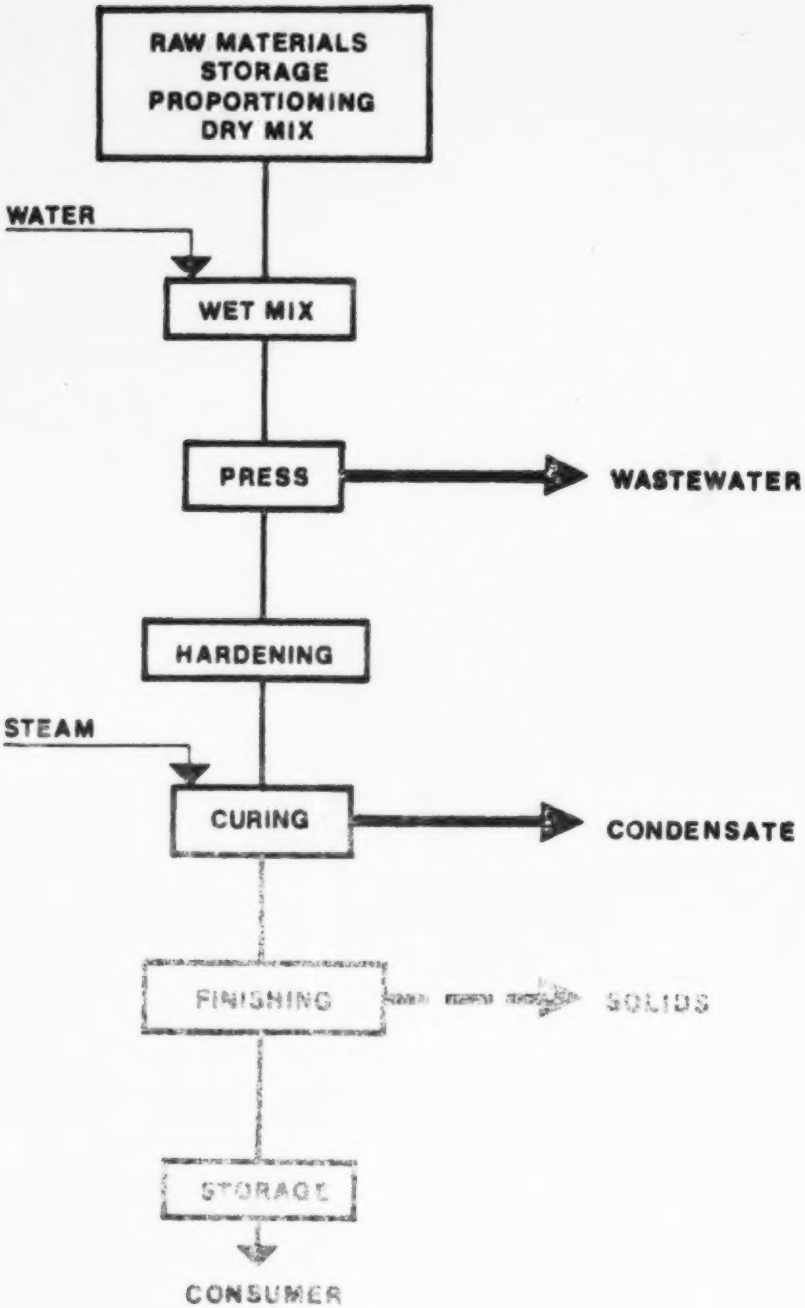

RAW MATERIALS
STORAGE
PROPORTIONING
DRY MIX
WATER
WET MIX
PRESS
WASTEWATER
HARDENING
STEAM
CURING
CONDENSATE
FINISHING
SOLIDS
STORAGE
CONSUMER

Figure 9.3. Asbestos-Cement Sheet Manufacturing Operations, Wet Process (Carton, 1974)

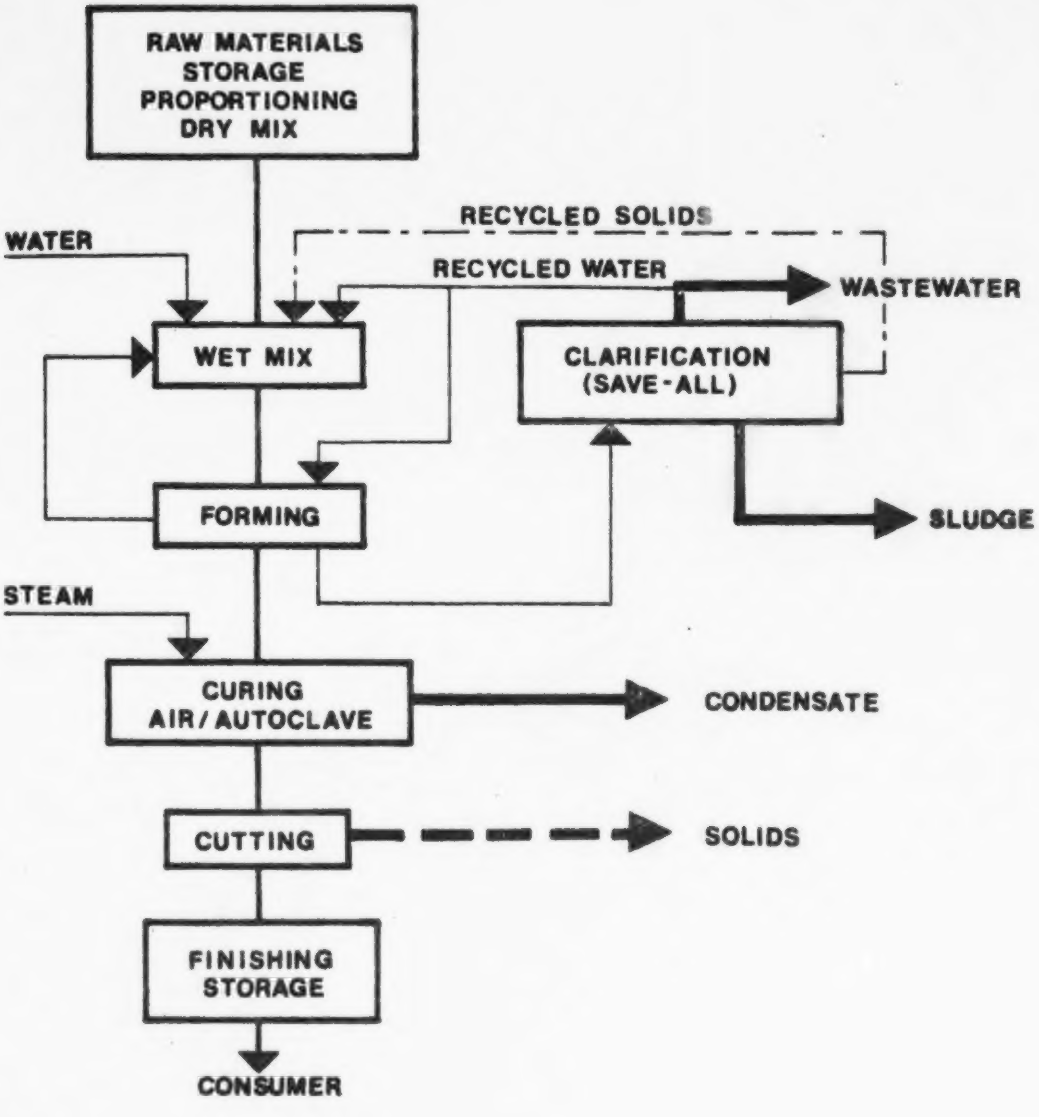

RAW MATERIALS STORAGE PROPORTIONING DRY MIX
WATER
RECYCLED SOLIDS
RECYCLED WATER
WASTEWATER
WET MIX
CLARIFICATION (SAVE-ALL)
FORMING
SLUDGE
STEAM
CURING AIR/AUTOCLAVE
CONDENSATE
CUTTING
SOLIDS
FINISHING STORAGE
CONSUMER

Figure 9.4. Asbestos-Cement Sheet Manufacturing Operations, Wet Mechanical Process (Carton, 1974)

The product is packaged in containers ranging from 5 gallon pails to tank cars. There are a large number of these coating plants. They vary in size, with about 3 million gallons per year as a maximum.

9.3 Quantities of Asbestos Released to the Environment from Manufacture

Listed in Table 9.3 are the estimated quantities of asbestos released to the environment from asbestos roofing product manufacture. An attempt has been made to eliminate overlapping of end-uses; for example, manufacturing losses from production of asbestos paper and A-C sheet used in roofing products will be considered in this section while production of these products for uses other than roofing will be considered in another appropriate section. The summary at the end of this report will bring appropriate figures together. The estimates in Table 9.3 were made by methods which are explained below. These estimates assume emission control techniques outlined fully in EPA (1973) publication.

9.3.1 Release from A-C Sheet and Shingle Production

First, it is assumed that about 125,000 short tons of A-C sheet and shingles are annually produced for roofing purposes. Applying the same release calculation methods as detailed in section 7.3.1, about 2,050 tons of asbestos are released as rejected product and scrap and about 142 tons of asbestos are released from baghouse collections. Similarly, using the same methods detailed in sections 7.3.1 and 8.3.2, the amounts of fiber released in process wastewaters and baghouse emissions are calculated to yield the results shown in Table 9.3.

9.3.2 Release from Asbestos Paper Production

The methods for calculating the release of asbestos from process wastewaters from asbestos paper production are detailed in section 10.3.1 and

Table 9.3 Estimated Environmental Release of Asbestos from Asbestos Roofing Production (SRC Estimates)

	Quantity (short tons)	Comment
To Waste, Dump or Landfill:		
1) A-C Sheet & Shingle Prodn.		
a. rejected product & scrap	1525	fibers in cement matrix
b. baghouse fines	105	free-fibers or matrix containment
c. process wastewater solids	74	fibers coated with cement
2) From Asbestos Paper Prodn.		
a. rejected product & scrap	n.a.	small as it can be recycled
b. baghouse fines	968	free-fibers
c. process wastewater solids	1961	fibers matted together by starch or elastomer binder, but free-fibers are a definite possibility
3) From Paper Coating Operations		
a. rejected product & scrap	1900	coated asbestos paper
b. baghouse fines	n.a.	see section 9.3.3
4) From Asphalt Mastic		
a. baghouse fines	36	free-fibers which can be recycled
b. rejected product & scraps	180	fibers bound in asphalt mastic
To Water		
1) From A-C Sheet & Shingle Prodn. from process wastewater	1.9	fibers coated with cement
2) From Asbestos Paper Prodn. process wastewater	38-80	free-fibers with some coating of starch or elastomer binder
3) From Paper Coating Operations from process wastewater	n.a.	probably small, see section 9.3.3
To Air From Baghouse Emissions		
1) From A-C Sheet & Shingle Prodn.	0.01-1.5	free-fibers
2) From Asbestos Paper Prodn.	0.1-2.1	free-fibers
3) From Paper Coating Operations	n.a.	probably small, see section 9.3.3
4) From Asphalt Mastic	.0036-1.0	free-fibers

will, therefore, not be included here. Applying these methods with the assumption that 85% of the asbestos fiber consumed in roofing applications (253,000 tons) is for paper production, then the quantities shown in Table 9.3 can be directly computed.

Rejected papers, scraps, and trimmings are apparently not wasted in significant amounts; Carton (1974) states that trimmings, defective paper, and other waste paper can usually be returned to the beater and repulped for recycling.

There is no direct monitoring data on which to base estimates for releases from baghouses used exclusively for asbestos paper production. However, it may be possible to apply certain relationships to baghouse parameters as detailed in section 7.3.1. Harwood and Ase (1977) determined that about one short ton per day of baghouse fines is collected per 220 short tons of A-C pipe production; this collection represents about 0.45% of the production quantity. Applying this 0.45% figure to asbestos paper production, it can be determined that about 968 tons of asbestos fibers are collected by baghouses. Similarly, using the Siebert et al. (1976) baghouse efficiency of 99.99%, it can be calculated that about 0.1 ton of very short asbestos free-fibers is emitted by these baghouses each year. Also, using the relationship of 1.34 lbs. of fibers emitted per year per 100 CFM rating, as developed in section 7.3.1 for baghouses, it can be estimated that perhaps 2.1 tons of fibers may be emitted by baghouses; however, as explained in section 7.3.1, this figure is probably too high.

9.3.3 Release from Asphalt and Paper Coating Operations

Most asbestos roofing is made by saturating heavy grades of asbestos paper with asphalt or coal tar, with the subsequent application of various surface treatments. The stock paper may be single or multiple layered and usually contains mineral wool, kraft fibers, and starch, as well as asbestos. Fiberglas filaments or strands of wire may be embedded between layers for reenforcement (Carton, 1974).

Unlike the asbestos operations covered previously, water is not an integral part in the asphalting or coating operation. Water is used to cool the roofing after saturation. All plants use non-contact cooling and some use spray contact cooling. The roofing is largely, but not completely, inert to water and the contact cooling water becomes a process wastewater (Carton, 1974). However, monitoring of this wastewater has not been done as Carton (1974) monitored a roofing plant using non-asbestos paper. It would seem that releases of asbestos fibers by this operation would be very small in quantity as the roofing paper has already been coated. Monitoring data are desirable.

As far as the asbestos fibers are concerned, these coating operations are really secondary manufacturing steps; that is, the greatest potential for fiber release has already occurred in the primary manufacturing. There are no useable monitoring data available for estimating quantities of baghouse fines or emissions which may occur from coating the asbestos paper. It would seem, however, that these quantities would be only a small fraction of the totals estimated for paper production.

Likewise, there are no monitoring data available for estimating the amount of rejected roofing paper and scraps. Harwood and Ase (1977) have determined that about 5-10% of asbestos-cement production is scrapped due to breakage or quality. This figure seems much too high to apply to roofing paper. An engineering estimate of 1% would seem to be more appropriate;

therefore, about 1,900 tons of asbestos are usually scrapped in roofing paper rejects. It is assumed that these scraps are disposed of in dumps or landfills.

9.3.4 Release from Mastic Asphalt Mix Production

The mixing of asbestos fibers with asphalt to make a mastic mix useable in roof coatings does not involve the use of any process water. Therefore, there are obviously no fiber emissions from a process wastewater source.

The primary release of fibers in this overall production probably occurs during bag opening and initial asphalt mixing (Daly et al., 1976). After the fibers have been incorporated into the asphalt, release during manufacturing is virtually nonexistent.

The change in the Bureau of Mines' asbestos consumption figures for coatings from 1974 to 1976 was about 18,000 tons (Clifton, 1975, 1977). We assumed that this is approximately the amount of asbestos used in roof coatings. However, there are no data available by which to make direct estimations of baghouse collections and emissions or product rejects. The baghouse estimation method developed in section 9.3.2 does not appear to be applicable to the asphalt mastic mix because process steps such as trimming and calendering, which contribute fiber to the baghouse, are not done. If we lower the collection factor to 0.2%, the results obtained are probably more realistic. Therefore, we can estimate that about 36 tons of asbestos fibers are collected by baghouses. Applying the Siebert et al. (1976) baghouse efficiency of 99.99% indicates that .0036 ton or 7.2 lbs. of fibers are emitted. The alternate method for predicting baghouse emissions given in section 7.3.1 would estimate emissions to be on the order of one ton.

Assuming product rejects and scrap total about 1% of production, then 180 tons of asbestos would be wasted to dumps or landfills.

9.3.5 Overall Considerations

The figures estimated in the previous subsections apply only to roofing products. There are additional releases involved in the production of A-C sheet, asbestos paper, and coatings for purposes other than roofing. Those releases are dealt with in their respective sections. It should also be remembered that these roofing operations are usually located in multi-asbestos product plants and that the estimations are only partial to the total plant losses.

An appropriate question which should be asked is, what happens to asbestos fiber which is released to the environment?

The eventual fate visualized is that the airborne material would settle, be picked up by rain or melting snow and passed on into streams and rivers with the waste water effluent, and finally lodge in river and lake beds, harbors, beaches, and shoals in these various bodies of water. The buried landfill and trash dump material may be stabilized with accompanying substances. As mentioned earlier in section 7.3.1, asbestos waste piles are potential sources of atmospheric fiber emissions.

9.4 Release of Asbestos from Installed Roofing Products

Asbestos roofing products are subject to weathering. Usual life is 15 to 25 years. Weathering results in changes in the asphalt or cement binder with little loss of asbestos. New roofing may be applied over the old. Tearing off of the old roofing is done when the old roofing has deteriorated to an extent to prohibit applications of new build-up or when the roof structure needs repairs for leaks or rot. The asbestos is therefore principally released with the scrapped material when discarded to landfill or trash dump where the scrap is buried. It is estimated that the annual quantity of this scrapped asbestos would be approximately 75% of the total consumption or about 200,000 tons.

Some scrap material may be incinerated during which the asbestos could possibly be released in the combustion gases or in the incinerater ashes. Loss with combustion gases should be controlled by scrubbing. If not destroyed during incineration, the asbestos in the product could be released as the ashes are used - such as in fertilizing or in making cement blocks. It is not possible to evaluate possible losses for these alternatives.

It is conceivable that some fraction of the roofing products might deteriorate in use to smaller particles that would wash away with rain or snow, or would be fine enough to become airborne. There are no monitoring data available, however, which have monitored for asbestos release from roofing materials during use. Most detachments from use of roofing materials are reported to be as large pieces of asphalt covered material (Fricklas, 1977). The amounts of asbestos which may become detached in free-fiber form, if any, are not known.

The following hypothetical calculation is made to estimate a theoretical magnitude of contamination, from roofing wear, by applying various assumptions. The following assumptions are made:

1) the concentration of exposed roofing products and their annual consumption follows population density;
2) 75% of annual consumption is used as replacement;
3) 0.1% of the asbestos in roofing products is detached from the product by weathering or other forces in free-fiber form;
4) annual use of asbestos in roofing is 253,000 tons.

Syracuse, with a population of 185,000, is chosen as the example city. Applying the above assumptions, the detachment of asbestos from roofing in Syracuse would be:

$$253{,}000 \frac{\text{tons}}{\text{year}} \times \frac{185{,}000 \text{ (Syr. pop.)}}{210{,}000{,}000 \text{ (U.S. pop.)}} \times .75 \text{ (replace.)} \times 0.001 \text{ (detach.)} =$$

$$0.156 \frac{\text{tons}}{\text{year}} = 0.85 \frac{\text{lb}}{\text{day}} = 3.88 \times 10^{11} \frac{\text{ng}}{\text{day}}$$

Assuming that the daily detachment of asbestos becomes equally distributed in the ambient air up to 1,000 ft. above the 25.8 sq. mile area of Syracuse, the daily emissions of asbestos would raise the ambient air concentration by 18 ng/m^3 for static air flow conditions.

Assuming further that the 18 ng/m^3 are washed from the air by 0.5 inches of rain (8.5×10^8 liters/25.8 sq. miles), the asbestos liter concentration of the fallen rain would be roughly 4.5×10^5 fibers/liter as shown below:

$$\frac{3.88 \times 10^{11} \frac{\text{ng}}{} \times 10^3 \frac{\text{fibers}}{\text{ng}}}{8.5 \times 10^8 \text{ liters}} = 4.5 \times 10^5 \text{ fibers/liter}$$

The above calculations are totally hypothetical and are not based upon any monitoring data. However, emissions of asbestos fibers due to weathering may be a potential source of release and warrant field check.

Losses during installation and laying the material are not considered to be significant. The asbestos fibers are encased by asphalt or cement. Field fabrication of asbestos-cement can release some dust during fitting and cutting operations; however, these fabrications are usually done by central fabricating shops as explained in section 8.4. The scrap made by cutting and fitting is wasted to landfills and dumps.

In summary, release of asbestos from installed roofing products appears to be essentially in the worn out material that is scrapped - with eventual fate in landfill and trash dumps. Field checks on air during trash dumping, shredding, and incineration operations seem to be indicated, as well as the atmosphere in very high density urban locations. Adherence to work practices outlined in EPA (1978) publication and approved amendment to Clean Air Act of 1977 should be checked.

9.5 Alternatives to Asbestos Roofing Products

The main roofing product, asbestos asphalt felt, could be replaced by the plain asphalt product without serious effects, since the asbestos product is a small percentage of the entire application. The price at $20 per roll is twice that of plain felt. When used, the added cost of asbestos asphalt felt is justified by its longer life and repairability and by its higher fire code rating.

Asbestos-cement sheet costing about the same per square foot is used largely as roof panels for industrial buildings in place of other more costly construction. Replacement by metal or plastics could be made at an additional expenditure.

Asbestos as an ingredient to roof coating and sealant compounds is unique in that it adds stability to the covering. Due to the fineness of the asbestos fibers, the strength and stability are increased. No other replacement, such as glass fiber, is as effective.

10.0 ASBESTOS PAPER

Asbestos paper is a very versatile product and therefore has a great variety of applications. In the electrical industry asbestos papers are used to fabricate paper tubes and tapes for insulating purposes. The asbestos content of the paper imparts the thermal and electrical resistance necessary for its effectiveness as insulation and fire protection for electrical conductors. Other electrical uses include special laminations for switchboard use, electrofine paper, and diaphragms for brine electrolysis cells (Carton, 1974; Daly et al., 1976).

Coarse grades of asbestos paper are impregnated with bitumen and used for roofing felts (see Section 9.0) and pipe wrapping. Pipe wraps are used to provide corrosion-resistant barriers for pipelines and piping. Corrugated asbestos paper sheets and blocks, usually made up of alternate plies of corrugated and plain paper, are employed for appliances at temperatures of up to 300°F. Formed into sectional pipe insulation, this material is used for insulating hot-water pipe, low-pressure steam pipe, and process lines within its temperature limit (Neisel and Remde, 1966).

Latex-bound asbestos papers are extensively used in the flooring industry as underlayments for sheet vinyl (Daly et al., 1976).

Other uses of asbestos papers include fabrication of gaskets, general insulations, beverage filters, molten glass handling equipment, general heat-fireproof components, and gas-vapor ducts for corrosive compounds.

Asbestos millboard is considered by some to be a very heavy paper and is in fact very much like thick cardboard in texture and structural qualities. It can be cut or drilled and can be nailed or screwed to a supporting structure

(Carton, 1974). It is generally used for insulating purposes or for specialty gasketing.

10.1 Use Quantities and Industrial Firms

According to Table 4.9 (p. 46), U.S. demand for asbestos in paper products has ranged from 14 to 66 thousand short tons annually during the 1967-1976 period. However, because asbestos paper is used in many secondary asbestos manufacturing products such as roofing, insulation, and gaskets, it is believed that the above asbestos demand for paper is much lower than the actual consumption. As explained in section 9.0, the consumption figures for asbestos roofing are thought to reflect the amount of asbestos fiber used to produce the paper which is in turn used to make asbestos roofing. From a survey of the asbestos industry, Daly et al. (1976) have estimated that 38% of the annual asbestos consumption is used to produce asbestos papers. Based on the total asbestos consumption of 725,000 tons in 1976, the amount, according to Daly estimates, of asbestos consumed in paper would be 276,000 tons. Table 10.1 below gives the estimated quantities of asbestos fibers used for all paper products in 1976.

Table 10.1. 1976 Asbestos Consumption in Paper Products (SRC Estimates)

Product	Quality (10^3 tons)	
Roofing	215	(from Section 9.0)
Gaskets	8	(from Section 13.3)
Insulations	6.6	(from Section 12.3)
All Other	31	(from Table 4.9)
	260.6	

The total estimated in Table 10.1 reflects a general agreement with the data obtained by Daly et al. (1976). It should be noted that asbestos millboard figures are incorporated into Table 10.1. Igwe (1974) estimated that about 15 tons of millboard are produced daily; on an annual basis this represents about 4,500 tons of production. While it is believed (SRC estimate) that millboard production may be somewhat higher than 4,500 tons per year, it still represents only a small fraction of the asbestos papers.

The Census Bureau does not have separate listings for all asbestos paper products; however, the data which are available from the Census Bureau for asbestos paper are given in Table 10.2.

Table 10.3 lists the major manufacturers of asbestos paper along with their respective locations. Most of the plants have diversified product lines.

10.2 Manufacturing Process Technology

Ingredient formulas for asbestos papers vary widely depending upon the intended use of the paper. The asbestos content of the finished paper may vary from 5% to essentially 100%, but a 70-90% content appears most common (Daly et al., 1976; Carton, 1974). Nearly all of the asbestos employed in papermaking is of the chrysotile variety, grades 4 through 7. Several hundred tons of crocidolite asbestos are annually used, primarily to make paper discs for automobile transmissions (Clifton, 1977). The binder content of asbestos paper accounts for 3-15% of its weight. The two major binder groups are starches and elastomers; less frequently used binders can include glue, cement, and gypsum. Choice of asbestos and binder content depends upon the desired properties and intended applications of the paper. Mineral wool, fiberglas, cellulose,

Table 10.2. Quantity and Cost of Asbestos Used in Paper and Millboard Products (U.S. Bureau of the Census, 1972)

SIC Product Code	Description	Materials Consumed			
		1972		1967	
		Quantity (1000 tons)	Delivered Cost (million $)	Quantity (1000 tons)	Delivery Cost (million $)
2621	Papermills, except Building Paper				
	Asbestos	-	1.8	-	-
2661	Building Paper and Board Mills				
	Asbestos	130.7	14.0	99.8	10.0

Table 10.3. Major Manufacturers of Asbestos Paper (Carton, 1974; Stewart *et al.*, 1976; industry communications)

Manufacturer	Location
Johns-Manville	Pittsburg, Calif. Waukegan, Ill. Manville, N.J. Fort Worth, Tex.
Celotex Corp.	Linden, N.J. Cincinnati, Ohio
Armstrong Cork	Fulton, N.Y.
Nicolet Ind.	Ambler, Pa. Hamilton, Ohio Norristown, Pa.
GAF Corp.	Erie, Pa. Whitehall, Pa.
Hollingsworth and Vose	E. Walpole, Mass.

latex, and many other constituents can be used to provide special properties and may represent as much as 15% of the paper's weight (Daly et al., 1976; Carton, 1974).

Figure 10.1 illustrates the typical manufacturing operation for production of asbestos paper. The process is actually quite similar to that of A-C pipe, especially in terms of potential environmental emissions. A brief description of the process is given in section 9.2, and will therefore not be included here.

Asbestos millboard is manufactured almost identically to paper. A flow diagram is included in section 12.2.

10.3 Quantities of Asbestos Released to the Environment from Manufacture

Listed in Table 10.4 are the estimated quantities of asbestos released to the environment from asbestos paper manufacture. Please note that the estimates in Table 10.4 do not include releases from paper made for roofing, insulation, or gasket purposes; releases from these purposes are given in sections 9, 12, and 13, respectively. The estimates are based upon the 1976 consumption of 31,000 tons of asbestos as listed in Table 4.9 (Clifton, 1977).

The estimates in Table 10.4 were derived by methods which are explained in the following subsections.

10.3.1 Release from Process Wastewaters

The raw water discharge from a typical asbestos paper manufacturing process contains about 19 pounds of suspended solids per ton of product produced (Carton, 1974). For asbestos paper production we have assumed that the suspended solids are approximately 80% asbestos fibers because the average asbestos content of the raw materials is about 80%. It is also assumed that the clarifiers which settle the suspended solids are 96% efficient

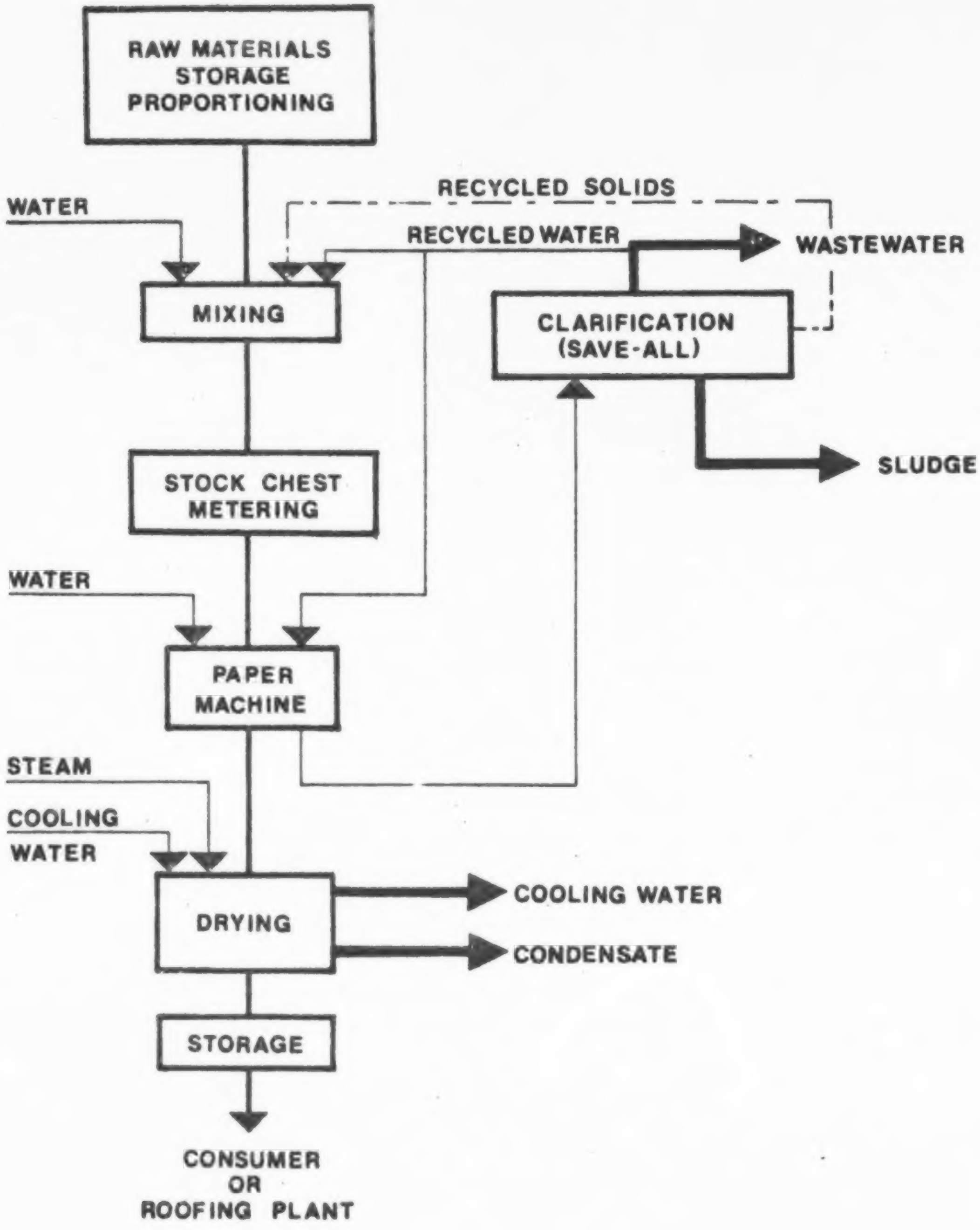

RAW MATERIALS
STORAGE
PROPORTIONING
WATER
RECYCLED SOLIDS
RECYCLED WATER
WASTEWATER
MIXING
CLARIFICATION
(SAVE-ALL)
SLUDGE
STOCK CHEST
METERING
WATER
PAPER
MACHINE
STEAM
COOLING
WATER
DRYING
COOLING WATER
CONDENSATE
STORAGE
CONSUMER
OR
ROOFING PLANT

Figure 10.1. Asbestos Paper Manufacturing Operations
(Carton, 1974)

Table 10.4. Estimated Annual Environmental Releases of Asbestos from Paper Manufacture* (SRC Estimates)

	Quantity (short tons)	Comment
To Waste Dump or Landfill:		
rejected product and scrap	n.a.	small as it can be recycled; see section 10.3.2
baghouse fines	140	free-fibers
process wastewater solids	283	fibers matted together by binders, but free-fibers are a possibility
To Water:		
from process wastewater	5.4-11.6	free-fibers with some binder coating
To Air:		
from baghouse emissions	0.014-1.0	free-fibers

---

*Does not include asbestos roofing, insulation, or gasket paper.

(Carton, 1974), and that about 38,750 tons of asbestos paper products are annually produced for purposes other than roofing. The efficiency factor for the clarifiers may be questionable, as explained in Section 7.3.2. The 38,750 ton figure was estimated by assuming that 31,000 tons of raw asbestos fiber are annually consumed for purposes other than roofing, etc. (from Table 10.1) and by assuming that the finished paper product is 80% asbestos on average. Therefore:

$$38{,}750\ \frac{\text{ton product}}{\text{yr}} \times 19\ \frac{\text{lb solids}}{\text{ton product}} \times 0.8\ \frac{\text{lb. asbestos}}{\text{lb solid}} \times .96\ \text{eff.} = 5.65 \times 10^{5}\ \frac{\text{lb}}{\text{yr}}$$

$$\text{or } 283\ \frac{\text{tons asbestos settled by clarifiers}}{\text{yr}}$$

Unlike asbestos-cement product plants, asbestos paper plants do not use Portland cement, and the solids in the clarifiers (save-alls) do not tend to form solid concretions. Hence, free-fiber release from the clarifier sludge may be possible. While a certain portion of the waste solids may be recirculated, this is usually not practiced in the industry due to the use of both starch and elastomer binders which are not compatible. In general, most of the suspended solids (sludge) collected from clarifying units or ponds are disposed in landfills; this was the practice noted by most asbestos paper plants field tested by Stewart et al. (1976). Two asbestos paper plants field tested by Stewart et al. (1976) released process wastewater to local sewer systems.

For cellulosic papers, it has been reported that product losses in the wastewaters should be somewhat less than 1% of production (Whitney et al., 1967). Note that the figure of 283 tons calculated by the above method is 0.9% of production, which is in good agreement with the percentage reported by Whitney et al. (1967).

The water effluent from the clarifiers also contains asbestos fiber; the quantity of asbestos released via this source has been estimated by two separate methods. Many asbestos paper plants recirculate water from the wastewater treatment facility back to the process and the effluent volume is considerably less than the raw water discharge; an effluent flow of 3300 gals./ton product, at exemplary plants, has been reported by Carton (1974). Carton has also reported that the raw water discharge contains 680 mg/liter suspended solids before clarification. After clarification, with a 96% efficiency, the water would contain 27.2 mg/liter. Therefore, the following computation can be made to estimate the amount of asbestos fiber released to water:

$$38{,}750\ \frac{\text{ton product}}{\text{yr}} \times 3300\ \frac{\text{gal discharge}}{\text{ton product}} \times 27.2\ \frac{\text{mg}}{\text{liter}} \times 3.785\ \frac{\text{liter}}{\text{gal}} \times 0.8\ \frac{\text{lb asbestos}}{\text{lb solid}} \times$$

$$\frac{\text{1 lb solid}}{\text{453600 mg}} \times \frac{\text{1 ton}}{\text{2000 lb}} = 11.6\ \frac{\text{tons asbestos Discharge to water}}{\text{yr}}$$

The second method of estimating asbestos release in water effluents is based upon monitoring data of asbestos concentrations. The level of asbestos in the final effluent has been measured at 10^8-10^{12} fibers per liter by Stewart *et al*. (1976) in field testing of six separate asbestos paper plants. The wide range was apparently caused by differing methods of waste treatment. Using an average of 10^{10} fibers per liter, the following calculation can be made:

$$10^{10}\ \frac{\text{fibers}}{\text{liter}} \times 3.785\ \frac{\text{liter}}{\text{gal}} \times \frac{10^{-9}\ \text{grams}}{10^{3}\ \text{fibers}} \times 3300\ \frac{\text{gal discharge}}{\text{ton product}} \times 38750\ \frac{\text{ton product}}{\text{yr}} \times$$

$$\frac{\text{1 ton}}{9\times10^{5}\ \text{grams}} \cong 5.4\ \frac{\text{tons asbestos discharge}}{\text{yr}}$$

"Of the industrial locations sampled, plants manufacturing asbestos paper present the greatest potential for contamination of surface waters by asbestos" (Stewart et al., 1976).

10.3.2 Release from Process Scraps and Baghouses

Rejected papers, scraps, and trimmings are apparently not wasted in significant amounts; Carton (1974) states that trimmings, defective paper, and other waste paper can usually be returned to the beater and repulped for recycling. It would seem possible, however, that a small amount of waste paper may be wasted to landfills. This potential quantity is difficult to estimate because there is no available data on which to base estimates. The best assumption appears to be that only a very small percentage of production is wasted.

As explained in section 9.3.2, there are no direct monitoring data on which to base estimates for releases from baghouses used exclusively for asbestos paper production. However, it may be possible to apply the Harwood and Ase (1977) monitoring data, for A-C pipe baghouses, that about 0.45% of production quantities is collected by baghouses. It has been previously noted that the production operations of A-C pipe and asbestos papers are very similar. Applying this 0.45% figure to asbestos paper production, excluding roofing paper, etc., it can be determined that about 140 tons of asbestos fibers are collected by baghouses. A percentage of this collection may be recycled to the process; however, Table 10.4 assumes that all collection is wasted.

Using the Siebert et al. (1976) baghouse efficiency of 99.99%, it can be calculated that about 0.014 tons of very short fibers are emitted annually by these baghouses. Another way of calculating fiber emissions is by using the relationship of 1.34 lbs of fibers emitted per year per 100 CFM rating, as developed in section 7.3.1 for baghouses. Using this value, it can be estimated that perhaps a ton of fibers may be emitted annually.

10.4 Release of Asbestos From Use of Paper Products

The potential release of asbestos fibers from use of various paper products is partially covered in other sections of this report. Roofing paper is discussed in section 9.4, insulation paper in section 12.4, and gasket paper in section 13.4. These uses represent over 88% of the annual asbestos consumption in papers. Potential fiber release from other uses of asbestos papers is discussed below.

10.4.1 Floor Underlayments and Pipe Wraps

Latex-bound asbestos papers are extensively used in the flooring industry as underlayments for sheet vinyl (Daly *et al*., 1976). Due to the application of the paper beneath the vinyl flooring, it is difficult to envision any fiber release during actual use. Installation of the paper may result in some fiber release or exposure to workers; however, there is no monitoring data to confirm or reject this supposition. As is the case for most asbestos products, the predominate amount of asbestos fiber content is wasted to landfills when product replacement is done. It is estimated that this type of flooring may require replacement every ten to twenty years, and that perhaps 75% of annual production is intended for replacements.

Another large-scale use of asbestos papers is for pipe wrappings to provide a corrosion-resistant barrier. Again, there is no monitoring data available to confirm or reject fiber release during use. Wrapped pipe which is buried in the ground will hardly be able to release airborne fibers;

however, it is possible that ground moisture may be able to attack the paper and allow some fibers to be leached out. Again, the major release of asbestos is considered to be to landfills at replacement time. Pipe wraps which are primarily used as insulation are discussed in section 12.4; there it is noted that in some pipe wraps the binder in the paper may breakdown from long-term use, thereby causing the material to become friable.

10.4.2 Diaphragms for Brine Cells

About 70% of the American chlorine production is produced by the diaphragm cell process (Treskon, 1976). In this electrolytic process of brine, the actual cathode surfaces are generally lined with a layer of asbestos either in the form of paper or of vacuum-deposited fibers (Deutsch *et al.*, 1963; Treskon, 1976). The function of the asbestos diaphragm is to maintain the NaOH strength and to minimize the diffusional migration of hydroxyl ions into the anolyte. All diaphragms gradually clog with the residual impurities that have not been removed from the brine and also with particles of graphite from the anode. The diaphragms are therefore renewed at regular intervals (Deutsch *et al.*, 1963). Typical renewal intervals of these asbestos diaphragms are 100 days or slightly longer (Dahl, 1975). It is assumed that worn-out asbestos diaphragms are disposed to landfills.

Deutsch *et al.* (1963) reports that asbestos consumption during cell operations is 1.20 lbs. per ton of produced chlorine. In 1976, about 10 million tons of chlorine were produced (U.S. Dept. of Commerce, 1977). Assuming that 70% of production used asbestos diaphragms, then approximately 4,200 tons of asbestos were consumed during electrolysis. This consumption is believed to be the total weight of the clogged asbestos diaphragms which are no longer useable and are, therefore, disposed of.

10.4.3 Beverage and Drug Filters

Asbestos paper pads are commonly used in the filtration of beverages (Biles and Emerson, 1968; Cunningham and Pontefract, 1971; Wylie, 1973). Types of beverages which are filtered with asbestos include beer, wine, and soft drinks.

An asbestos filter sheet is a specialized filter material which is used for small to medium size operations requiring the removal of small quantities of fine or very fine solids; these filter sheets are mainly used to remove micro-organisms from liquids (Wylie, 1973). In addition to asbestos fibers, these filter sheets contain cellulose fibers and diatomaceous earths. They resemble filter paper 3.0 to 4.0 mm in thickness. Patents for asbestos filters were first obtained in 1918 in Germany. The essential ingredient, asbestos fiber, permits high permeabilities with really effective filtration properties.

The use of asbestos to filter liquids leads to the supposition that perhaps some free-fibers may be released during use, and, therefore, asbestos fibers may be present in the final beverage product which is consumed. Biles and Emerson (1968) identified asbestos fibers in commercial beer products with a rough concentration of 5,000 fibers per pint. However, it was assumed that the concentration was subject to a wide variation due to variability in commercial filtration processes. They also identified asbestos fibers in filtrates that were passed through asbestos filters.

Cunningham and Pontefract (1971, 1973) examined a wide variety of beverages which are filtered with asbestos. Their results are tabulated in Table 10.5 along with examinations of tap water, melted snow, and river water. Wehman and Plantholt (1974) detected asbestos in commercial gin.

Table 10.5. Asbestos Fibers in Beverages and Water (Cunningham and Pontefract, 1973)

Sample	Source[a]	No. of fibers/L,X10^6
Beer	Canadian 1	4.3
Beer	Canadian 2	6.6
Beer	USA 1	2.0
Beer	USA 2	1.1
Sherry	Canadian	4.1
Sherry	Spanish	2.0
Sherry	South African	2.6
Port	Canadian	2.1
Vermouth	French	1.8
Vermouth	Italian	11.7
Soft drink	Ginger ale	12.2
Soft drink	Tonic water I	1.7
Soft drink	Tonic water II	1.7
Soft drink	Orange	2.5
Tap water	Ottawa, Ottawa River (F)	2.0
Tap water	Toronto, Lake Ontario (F)	4.4
Tap water	Montreal, St. Lawrence River (F)	2.4
Tap water	Hull, Quebec, Ottawa River (NF)	9.5
Tap water	Beauport, Quebec, St. Lawrence River (6 km below Quebec City) (NF)	8.1
Tap water	Drummondville, Eastern Townships, Quebec, St. Francois River (F)	2.9
Tap water	Asbestos, Eastern Townships, Quebec, Nicolet River (F)	5.9
Tap water	Thetford Mines, Eastern Townships, Quebec, Lac a la Truite (NF)	172.7
Melted snow	Ottawa, top 30 cm (2-3 weeks precipitation)	33.5
River water	Ottawa River, at Ottawa	9.5

[a] F, Filtration plant used; NF, no filtration plant used.

The degree to which fibers are released to consumable beverages from asbestos filters cannot be quantified from the available data, although some high fiber counts have been noted. It may even be argued that the available data do not conclusively prove that asbestos fibers are released from filter pads. The reason is, in none of the studies available to date has the concentration of asbestos fibers in the water used to make the beverages been determined. Asbestos fibers are found in many surface waters, and it is possible that water used to make beverages contained fibers before the beverages were made. Therefore, the degree to which filters may contribute fibers to beverages cannot be determined without additional data.

Asbestos fibers have also been detected in parenteral drugs (Nicholson _et_ _al_., 1973). Parenteral drugs are drugs which are injected intravenously or intramuscularly. Several decades ago, the pharmaceutical industry found that asbestos filters are useful and effective for removal of foreign matter from parenteral solutions, and, therefore, these asbestos filters have become widely used. However, Nicholson _et_ _al_. (1973) identified chrysotile asbestos in approximately one-third of the samples from two sets of 17 widely used parenteral drugs. Once again the conclusion can be drawn that the presence of asbestos in the drug solution may be the result of asbestos filtration.

Although asbestos fibers were found in only one-third of the samples, Nicholson _et_ _al_. (1973) noted that negative or indefinite results for a particular sample did not guarantee the absence of asbestos in the drug lot from which the sample was taken. A single vial is an inadequate sample of a large production run. Additionally, the drugs sampled represented only a small fraction of those on the market.

It can be noted that in the U.S. no asbestos-containing or other fiber-releasing filter may be used in the manufacture, processing, or packing of such pharmaceuticals, unless it is not possible to manufacture that drug product or component without the use of such a filter (U.S. Food and Drug Admin., 1976).

10.5 Alternatives to Asbestos in Paper

In general, asbestos papers are unique due to the unequaled properties of asbestos fibers, namely heat, chemical, corrosion, and rot resistance coupled with dimensional stability. Substitution of the asbestos fiber by an alternative fiber, such as fiberglas, glass, ceramic, or other mineral fiber, may permit a useable product to be produced. However, the alternative fiber will be more costly and the performance will usually suffer. Within the economic restraints of the various markets, the substitution of asbestos by some alternative fiber in paper products is just not economically practical at present.

For some applications of asbestos papers, alternative products or methods are currently available. Alternatives to asbestos paper used in roofing, insulations, and gaskets are discussed in sections 9.5, 12.5, and 13.5, respectively.

An alternative to asbestos diaphragms in electrolytic cells has been developed and demonstrated by Hooker Chemical Co. (Dahl, 1975). The alternative is a membrane-cell consisting of a film of perfluorosulfonic acid resin (a copolymer of tetrafluoroethylene) and another monomer to which negative sulfonic acid groups are attached. The membrane-cells are more expensive than the asbestos diaphragms and are apparently still in a developmental stage. The overall economics of conversion to membrane-cells cannot be ascertained at this time; however, these cells appear to be a very viable alternative to asbestos diaphragms in future years.

Expanded perlite has been successfully used as a substitute for asbestos filters in some applications such as bulk liquid filtration (Fulmer, 1976). Perlite is a form of glassy rock similar to obsidian. It usually contains 65-75% SiO_2, 10-20% Al_2O_3, 2-5% H_2, and smaller amounts of soda, potash, and lime. When perlite is heated to the softening point, it expands to form a light fluffy material similar to pumice. Expanded perlite does not, however, replace asbestos in most cases.

11.0 ASBESTOS FLOORING

Asbestos floor tiles are produced in the United States for use in commercial applications, offices, and homes. The shortest grades of asbestos fibers are used in vinyl and asphalt floor tile manufacture. The asbestos fibers are used to impart strength, dimensional stability, and resistance tc the cold. At present, vinyl asbestos floor tile (VAT) accounts for most of the asbestos used in this category, with asphalt tile serving some special applications and applications where darker shades are permissible.

11.1 Use Quantity, Shipment Values, and Industrial Firms

U.S. demand for asbestos in flooring products has ranged from 113 to 218 thousand short tons annually during the 1967 to 1976 period; in 1976, 113 thousand short tons of asbestos were used in flooring products (Clifton, 1977). Only the chrysotile variety of asbestos is used. According to the 1976 figures, about 15.6% of the total U.S. market for asbestos was consumed in the production of flooring. This is the third largest use of asbestos fiber, ranking behind roofing and A-C pipe.

Table 11.1 lists the shipment values and quantities of asbestos floor tile as given by the Census Bureau. In 1967, asphalt-asbestos floor tile made up about 15% of the asbestos floor tile market compared to vinyl-asbestos tile's 85%; however, by 1972 the market for asphalt-asbestos tile had fallen to comprise only 5% of the asbestos floor tile values. Competitive pressures from alternative flooring products is the primary reason for the decline of the asphalt-asbestos market.

In fact, in recent years the vinyl-asbestos floor tile market has been less than spectacular as a result of strong competition from carpeting and

Table 11.1. Shipment Values and Quantities of Asbestos Floor Products
(U.S. Bureau of the Census, 1972)

SIC Product Code	Product	Total Product Shipments, including interplant transfer			
		1972		1967	
		Quantity (million sq yd)	Value (million $)	Quantity (million sq yd)	Value (million $)
32925 11	Asphalt Floor Tile	9.8	9.1	28.0	25.0
32926 --	Vinyl Asbestos Floor Tile	--	199.3	143.5	153.5
32926 13	Plain backed	129.4	151.3	143.5	153.5
32926 15	Adhesive backed	--	48.0		
32926 00	Vinyl asbestos, n.s.k.	--	--		

linoleum (Igwe, 1974). The market for all types of vinyl (PVC) flooring, which includes vinyl-asbestos and all other kinds of vinyl floorings, declined from about 50% of all basic floor coverings in 1961 to only 30% in 1971. As a point of reference, about 67% of all vinyl flooring in 1969 was of the vinyl-asbestos type (Frey, 1976). The phenomenal growth in the use of tufted carpets in both residential and commercial buildings is the main reason for the decline. However, vinyl flooring is now believed to have firmly established its market share according to 1971 figures (Frey, 1976). This implies that significant increases in the use of asbestos for flooring are not likely to occur in the foreseeable future.

Table 11.2 lists the major manufacturers of asbestos-flooring products along with their respective locations and estimated 1975 sales.

The 1976 floor tile consumption of 113 thousand tons of asbestos would produce roughly 105 million sq. yds. of asbestos flooring.

11.2 Manufacturing Process Technology

Floor tile manufacture involves proprietary production line processes highly developed by the individual manufacturers. Equipment layout, process description and compound formulations are held very confidential because the industry is highly competitive (Daly et al., 1976).

The asbestos content of the tile ranges from 8-30% by weight (Carton, 1974) and usually comprises very short fibers, grades 5 and 7 (Table 4.10, p. 46). Each square foot of tile may contain upwards of 0.13 pounds asbestos fibers (Daly et al., 1976). PVC resin serves as the binder and makes up 15-25% of the tile; chemical stabilizers usually represent about 1%. Limestone and other fillers make up 55-70% of the weight. Pigment content usually averages about 5%, but may vary widely depending upon the materials required to produce the desired color (Carton, 1974).

Table 11.2. Major U.S. Manufacturers of Asbestos Flooring

Manufacturer	Plant Location	Estimated 1975 Sales* of Asbestos Flooring (millions of dollars)
American Biltrite Rubber	LaMirada, Cal.	5.7
Armstrong Cork Co.	South Gate, Cal. Kankakee, Ill. Jackson, Miss. Lancaster, Pa.	36.5
Flinkote	Los Angeles, Cal.	20.3
	Chicago, Ill.	14.4
	New Orleans, La.	6.6
GAF Corp.	Long Beach, Cal.	14.4
	Joliet, Ill.	15.0
	Vails Gate, N.Y.	17.4
	Houston, Tex.	8.7
Kentile Floors	Brooklyn, N.Y.	29.5
	TOTAL	168.5

* Economic Information Systems, Inc.; SRC Estimates
Monetary values are in 1975 dollars.

Most floor tile manufactured today uses a vinyl resin, although some asphalt tile is still being produced. The manufacturing processes are very similar and the water pollution control aspects are almost identical for the two forms of tile (Carton, 1974). Figure 11.1 shows the general manufacturing process.

The ingredients are weighed and mixed dry. Liquid constituents, if required, are then added and thoroughly blended into the batch. After mixing, the batch is heated to about 150 degrees C and fed into a mill where it is joined with the remainder of a previous batch for continuous processing through the rest of the manufacturing operation. The mill consists of a series of hot rollers that squeeze the mass of raw tile material down to the desired thickness. During the milling operation, surface decoration in the form of small colored chips of tile (mottle) are sprinkled onto the surface of the raw tile sheet and pressed in to become a part of the sheet. Some tile has a surface decoration embossed and inked into the tile surface during the rolling operation. This may be done before or after cooling. After milling, the tile passes through calenders until it reaches the required thickness and is ready for cooling. Tile cooling is accomplished in many ways and a given tile plant may use one or several methods. Water contact cooling in which the tile passes through a water bath or is sprayed with water is used by some plants. Others use non-contact cooling in which the rollers are filled with water. In some plants, the sheet of tile passes through a refrigeration unit where cold air is blown onto the tile surface. After cooling, the tile is waxed, stamped into squares, inspected, and packaged. Trimmings and rejected tile squares are chopped up and reused (Carton, 1974).

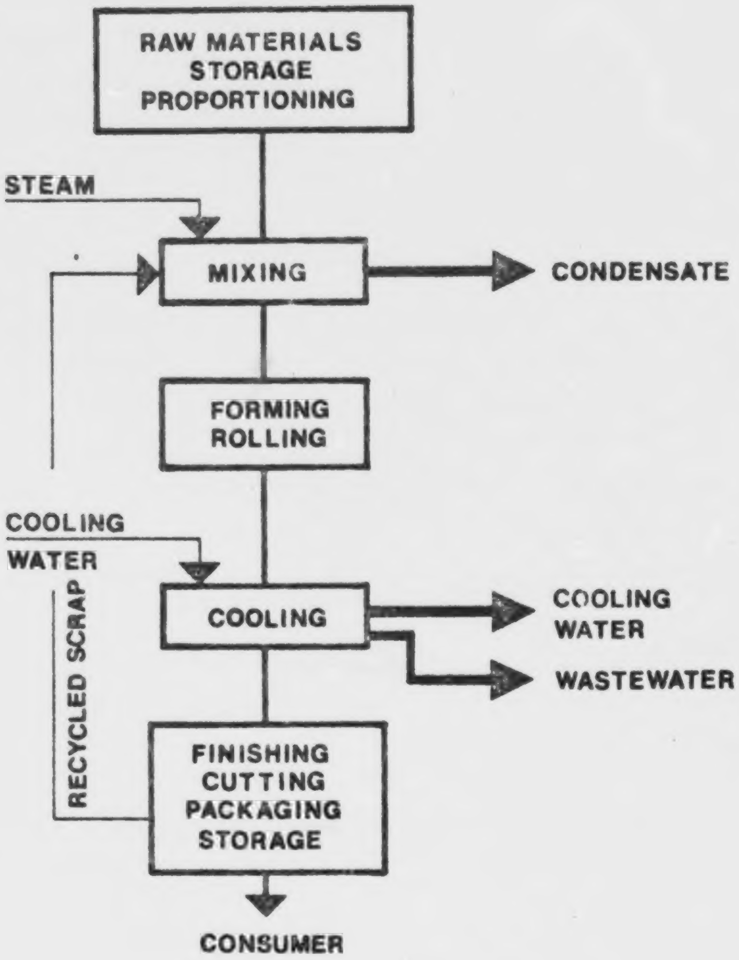

RAW MATERIALS
STORAGE
PROPORTIONING
STEAM
MIXING
CONDENSATE
FORMING
ROLLING
COOLING
WATER
RECYCLED SCRAP
COOLING
COOLING
WATER
WASTEWATER
FINISHING
CUTTING
PACKAGING
STORAGE
CONSUMER

Figure 11.1. Asbestos Floor Tile Manufacturing Operations (Carton, 1974)

11.3 Quantities of Asbestos Released to the Environment from Manufacture

In the manufacture of asbestos vinyl tile, water is used only for cooling purposes. Both contact and non-contact cooling are usually employed. Water does not come into contact with the tile until it has been heated and rolled into its final form. In this stage it is completely inert to water (Carton, 1974). Therefore, wastewaters will contain little, if any, asbestos fibers. Stewart et al. (1976) found asbestos concentrations of less than 10^6-10^7 fibers per liter in wastewaters from Armstrong's Kankakee, Ill. floor tile plant.

Additionally, trimmings and rejected tile squares are chopped up and reused. Therefore, there are only minor amounts of manufacturing scraps disposed to landfills.

The only major source of asbestos release to the environment from floor tile manufacture is from baghouses, both air emissions and collection dumpings. There are no direct data available by which to make direct estimations of these baghouse collections and emissions; however, the manufacturing process, in this regard, is similar to that of the mastic asphalt mix for roofing. As developed in section 9.3.4, it was estimated that perhaps 0.2% of production volumes, for the mastic roofing mix, were collected by baghouses. Applying this figure to floor tiles, about 227 tons of asbestos fibers are annually collected in baghouses. The Siebert et al. (1976) baghouse efficiency of 99.99% indicates that 0.0227 tons of fibers are emitted into the atmosphere annually. The alternate method for predicting baghouse emissions given in section 7.3.1 would estimate emissions to be on the order of one ton.

11.4 Release of Asbestos from Asbestos Flooring Use

By far, the major release of asbestos to the environment from flooring use occurs at replacement time when old flooring is removed and disposed to landfills. Service time for asbestos floorings depends upon the severity of use; accordingly, service life may vary from 10 to 30 years. Therefore, a healthy percentage of production is intended as flooring replacements. This percentage may be in the neighborhood of 40-60%.

During the service life of an asbestos floor various forces act upon it and the result may be a release of free asbestos fibers. Forces such as walking, scrapping, cleaning, and machine scrubbing may be sufficient to break-down the vinyl matrix and allow asbestos to escape. However, there has been no study conducted to determine if, or how much, asbestos may be released during use or cleaning. Such a study may be desirable.

The following hypothetical example of asbestos fiber release from flooring use is intended to illustrate a potential magnitude of emissions which can be theoretically calculated from various assumptions. Daly *et al*. (1976) have reported that each sq. ft. of tile may contain up to 0.13 lb asbestos; therefore, it is assumed that each sq. ft. of tile contains 0.13 lb asbestos. Additionally, the following assumptions are made: (1) the average service-life of an asbestos floor is 20 years; (2) approximately 10% of the flooring is worn away during the service-life by use and cleaning; and (3) about 1% of the "worn-away-flooring" becomes airborne. It is visualized that wear on the floor will not be even over the entire surface because sections may be covered may be covered by equipment, desks, etc.; however, it is assumed that sections of the floor which are worn away disperse airborne fibers uniformly throughout the entire room. Therefore, the following computation can be made which gives the amount of asbestos emitted per day, on average, from each square foot of asbestos tile:

$$0.13\ \frac{\text{lb asbestos}}{\text{ft}^2} \times \frac{0.10\ \text{wear}}{20\ \text{yrs}} \times 0.01\ \text{airborne} \times 453.6\ \frac{\text{grams}}{\text{lb}} =$$

$$0.003\ \frac{\text{grams emitted}}{\text{yr/ft}^2} = 3.6 \times 10^6\ \frac{\text{ng}}{\text{yr/ft}^2} = 8.2 \times 10^3\ \frac{\text{ng emitted}}{\text{day/ft}^2}$$

It is now assumed that each square foot of tile is installed 10 feet below the ceiling; therefore, each square foot is topped by 10 ft^3 of air. Assuming ventilation design requires 15 air changes per hour, then 1 ft^2 of tile will be topped by approximately 3600 ft^3 of air each day, which is equivalent to 102 m^3 of air each day. Therefore, assuming uniform mixing of air and airborne asbestos fibers, the average asbestos concentration of the air is raised daily by:

$$\frac{8.2 \times 10^3\ \text{ng emitted}}{102\ \text{m}^3} = 80\ \frac{\text{ng}}{\text{m}^3} = 8 \times 10^{-5}\ \frac{\text{ng}}{\text{cm}^3}$$

Using the conversion factor of 10^3 asbestos fibers per nanogram, the air concentration of 80 ng/m^3 is equivalent to 0.08 fibers/cm^3. The above assumptions predict that the average asbestos concentration of the air above an asbestos floor can theoretically be raised by daily use of the floor by 0.08 fibers/cm^3. This 0.08 fiber figure is based upon the estimation that 1 nanogram equals 10^3 fibers which is, in turn, based upon electron microscopy count. Rohl et al.

(1975) have indicated that the number of fibers visible by electron microscopy is perhaps one hundred fold as compared to an optical microscopy method which counts only fibers of 5 μm in length or longer. The optical microscopy method for counting fibers 5 μm or longer is used for determining compliance with OSHA regulations. On this basis, the concentration of fibers emitted by asbestos flooring, if measured by the OSHA optical microscopy method, in the above example would be 0.0008 fibers/cm^3.

It should be noted that the example given above is only supposition. Monitoring is required to determine actual concentrations, if any. Under practical conditions, it would be unlikely that all fibers released by use would become airborne. A large percentage would probably be incorporated into water used for cleaning purposes which would then be released into wastewaters. This is the reason for assuming that only 1% of worn material would become airborne.

11.5 Alternative Products to Asbestos Flooring

Asbestos flooring competes principally with carpeting, linoleum, and sold vinyl flooring. At present, about 95% of all asbestos flooring is vinyl-asbestos. As indicated earlier, in section 10.1, all types of vinyl floor coverings make up about 30% of the flooring market; and, in 1969, about two-thirds of the vinyl market was asbestos-vinyl. Therefore, in the late 1960's and perhaps, early 1970's, vinyl-asbestos flooring covered about 20% of the total flooring market. However, this 20% figure has decreased and is decreasing somewhat due to the popularity of various types of non-asbestos vinyl flooring. In recent years, coated types of vinyl flooring (plastisol-coated felts) have moved strongly into flooring markets of all cost levels at the expense of vinyl-asbestos tile (Frey, 1976).

The newer types of vinyl flooring are produced as roll goods and typically have a felt or other backing (e.g., asbestos felt coated with styrene-butadiene latex). This backing receives a foamed plastisol coating, the surface of which is decorated with a pattern by rotogravure printing or so-called chemical embossing, and then is covered with a clear plastisol wear layer (Frey, 1976).

Apart from reinforcing the final product, the asbestos fibers perform a function in giving the polymer sheets "wet-strength" during the manufacturing process (Green and Pye, 1976). Alternative fibers to asbestos do not have all of the performance characteristics unique to asbestos. As far as asbestos flooring is concerned, the alternative fibers mentioned in other sections of this report are potentially useable, but the final product is somewhat inferior and more expensive. Whether such a product is marketable at this time is doubtful.

12.0 ASBESTOS INSULATION

Asbestos used for thermal and electrical insulation materials amounted to 1 1/4% of the total U.S. output of asbestos products in 1976. The use was divided between the two classifications as follows (Clifton, 1977):

Thermal Insulation = 6600 tons
Electrical Insulation = 2300 tons
Total 8900 tons

The uses for insulation have dropped drastically from 25,000 tons/year in 1973, where it had held consistently for 10 years (Table 4.9). The decreased consumption has followed restrictions that recent health protective limitations impose (EPA, 1974). At the current consumption, asbestos insulating materials are less than 1% in value of the total market for all insulation materials. Projected trend is for further decrease in asbestos insulation because of health, as well as economic, disadvantages.

In spite of the small and decreasing current use of asbestos for insulation purposes and a possibility for nearly complete replacement, the disposition of the extensive, previously installed insulation materials for industrial and commercial buildings and equipment will continue to be an important source of asbestos release to the environment. Controls of these demolition procedures for old installations are an important factor in preventing release of the dangerous fibrous material to the environment (EPA, 1974).

12.1 Asbestos Insulation Products, Uses, and Economic Trends

Asbestos fiber is used for thermal insulation in a variety of forms and compositions to conserve energy, to control temperatures, and to protect personnel and equipment from elevated temperatures. Asbestos fiber is also used for electrical insulation in various forms where the system may be exposed to elevated ambient temperatures. As in many other applications, asbestos may be used also to increase the strength and durability of the insulation product (Neissel and Femde, 1966; Swiss, 1966).

The restriction in use for health reasons is changing the pattern for asbestos application significantly, and further reduction to lower consumption is visualized.

Before 1973 asbestos was used generally for insulation applications, up to about 850°F alone and in mixtures, and up to 1200°F with calcium silicate in preformed coverings. These uses applied to piping, boilers, tanks, reactors, furnaces, turbines, and other high temperature operations. For those purposes requiring specifically designed coverings, asbestos was fabricated in factory operations into sectional forms alone and with mixtures of other materials for easy field installation. Eighty-five percent magnesia pipe covering and batts with 15% asbestos fiber were typical forms for the products.

These products have been phased out (EPA, 1974) and are no longer produced. Asbestos for thermal insulation is produced only in the form of more common materials, i.e., paper, millboard sheet, and textile coverings, as well as loose powder for mixing with water and additives to form plaster. These materials are fabricated into required forms during installation at field locations.

For electrical insulation, asbestos was used in the form of paper, roving, webbing, and braid for systems where comparatively high ambient temperature may occur. Substitutes have been developed and are increasingly used due to health hazard restrictions. Woven asbestos covering continues to be used at decreasing rates for electric conductors exposed to high temperatures.

Asbestos fiber has also been used to reinforce plastics and ceramics in switch and connector boxes, terminals, and as paper to line junction and switch boxes.

A breakdown of the grades and types of asbestos used in the above products in 1976 is given in Table 12.1.

As with roofing, the finer grades of chrysotile are the principal constituents of the insulation products. Also, as in the case of all U.S. fabricated products, about 90% of the milled fiber is imported from Quebec, with only about 10% produced in the several U.S. mines in Vermont and the Southwest (Table 3.1).

U.S. producers of asbestos paper, millboard sheet, and spun fiber products that are potentially adaptable to insulation applications are listed in Table 12.2. However, with the exception of Johns-Manville at Waukegan, none are understood to be presently producing materials for thermal insulation (Barnhart, 1977).

The spun fiber products made in the listed plants may be used for electric insulation and principally for cable and wire covering by specialty and appliance fabricators.

In addition to the above manufacturers of prime asbestos materials, the 1975 Thomas Register lists about 50 companies selling insulation materials. These companies sell and fabricate various specialities made from the prime products. Some of these can be used for insulation purposes.

The value and quantities of the insulation materials for the past few years are summarized in Table 12.3. The figures for the more recent years are extrapolated from the data reported earlier. The 1974 and 1976 data include very few prefabricated factory products, such as were produced and included in the 1967 and 1972 figures.

Table 12.1. Distribution of Asbestos Minerals Used for Insulation (short tons) (Clifton, 1977)

Mineral Form and Grade		Thermal Insulation	Electrical Insulation
Chrysotile			
Group 3		---	100
Group 4		800	---
Group 5		200	100
Group 6		1900	200
Group 7		3600	1900
	Total	6500	2300
Crocidolite		---	---
Amosite		100	---
Anthophylite		---	---
	Total (tons/year)	6600	2300
	Total (%)	74	26

Table 12.2. U.S. Manufacturers of Asbestos Paper, Millboard, and Spun Fiber Adaptable for Insulation

A. Paper and Millboard (Carton, 1974)	
Johns-Manville	Waukegan, Ill. Manville, N.J.
Celotex Corporation	Linden, N.J. Cincinnati, Oh.
GAF	Erie, Pa.
Nicolet Industries	Hamilton, Oh. Amber, Pa.
B. Spun Fiber Products (Margolin, 1975)	
Johns-Manville	Manville, N.J.
Amatex Corporation	Meridith, N.H. Morristown, Pa.
Southern Asbestos	Charlotte, N.C.
Raybestos-Manhattan	North Charleston, N.C.

Table 12.3. Value of Asbestos Insulation Products (approximated from 1972 Census of Manufacturers Data)

			1967	1972	1974	1976
Total Annual Consumption[a]		1000 tons	22-	24-	14-	8.9
32927.35	Piping	$\$10^6$	17.3	20.7	10[b]	6.5[b]
32927.37	Block and others	$\$10^6$	8.8	12.8	5[b]	3.3[b]
	Total asbestos products	$\$10^6$	26.1	33.5[c]	15[b]	9.8[b]

(a) From Bureau of Mines figures (Clifton, 1977) for annual consumption. Bureau of Census data is for production. Interchangeable use assumes exports and imports are equal.

(b) Prorated from 1972 census data from Bureau of Mines production figures.

(c) The Asbestos Information of North America reported value at $40.9 million for 1971. (Asbestos, 1973)

Comparisons with 1972 U.S. Bureau of Census data for mineral fiber insulation and for fiber glass products indicate that present value of asbestos insulation would total not more than 1% of the value of all insulation materials produced. For example, the value of mineral wool insulation averaged as follows for 1967-1972:

For structural insulation	SIC 32961	=	$\$242 \times 10^6$
For industrial insulation	SIC 32962	=	329×10^6
	Total		$\$571 \times 10^6$

If other materials, such as organic fibers, are also included, a total annual value approaching $1000 million is visualized for the entire present insulation industry. Hence, at about $9.8 million, the annual value of asbestos materials is less than 1% the total and is decreasing.

12.2 Manufacturing Technology

The manufacture of insulation products may be considered under two categories, namely factory fabricated and field fabricated materials.

Factory fabricated insulation materials include especially preformed or molded articles produced as sectional parts for easy installation. These include sectional pipe covering, blocked batts, and molded parts that have been mixed and compounded with such materials as magnesia, calcium silicate, and plastics. Before 1973 asbestos fiber was added for temperature protection and strength. As explained earlier, uses of these asbestos materials have been phased out and are not currently used (EPA, 1974). Similarly, decreasing quantities of asbestos paper and millboard sheets continue to be produced for thermal insulation applications as part of the larger quantities of those materials produced for other purposes, such as roofing and building materials.

The manufacturing processes for paper are described in Section 9.2. The manufacture of asbestos millboard is shown diagrammatically by Figure 12.1 and is essentially the same as for asbestos paper by the cylinder machine process. For millboard, multiple layers of pulp are built up to about 1/2" by successively adding plies from a series of cylinders, followed by pressing, drying, and finishing. The products are about 95% asbestos. Uses of water for pulping and washing are the same as in paper making. Also, recycling water and the recovery of pulp and disposal to waste are the same as in paper making (Section 9.2 and Carlton, 1974).

Rope, roving, and other partly spun asbestos fiber materials used for electrical insulation are made by the same methods used in cotton and wool milling. The fiber is successively graded, carded, combed, and drawn to make roving and spun fiber (Labarthe, 1975; Margolin, 1975). Material for the ground and conductor insulation products may be taken at any point such as the combed mat, roving, thread, or twisted cords as rope, web, or braid. These are mechanical operations that can be hooded and ventilated with bag or other filters to collect released fiber. However, asbestos has been nearly completely replaced by other insulation for all electric uses with the exception of coverings for cable and wire and for appliance specialties where there is high temperature exposure.

Field fabrication of thermal insulation consists principally in adapting usual forms of asbestos material, such as paper and millboard sheets, to industrial equipment and structures. The installation varies with the shape of the equipment on which the insulation is installed. For piping, flues, and circular stacks, paper, millboard, cloth or tape is wrapped around the objects

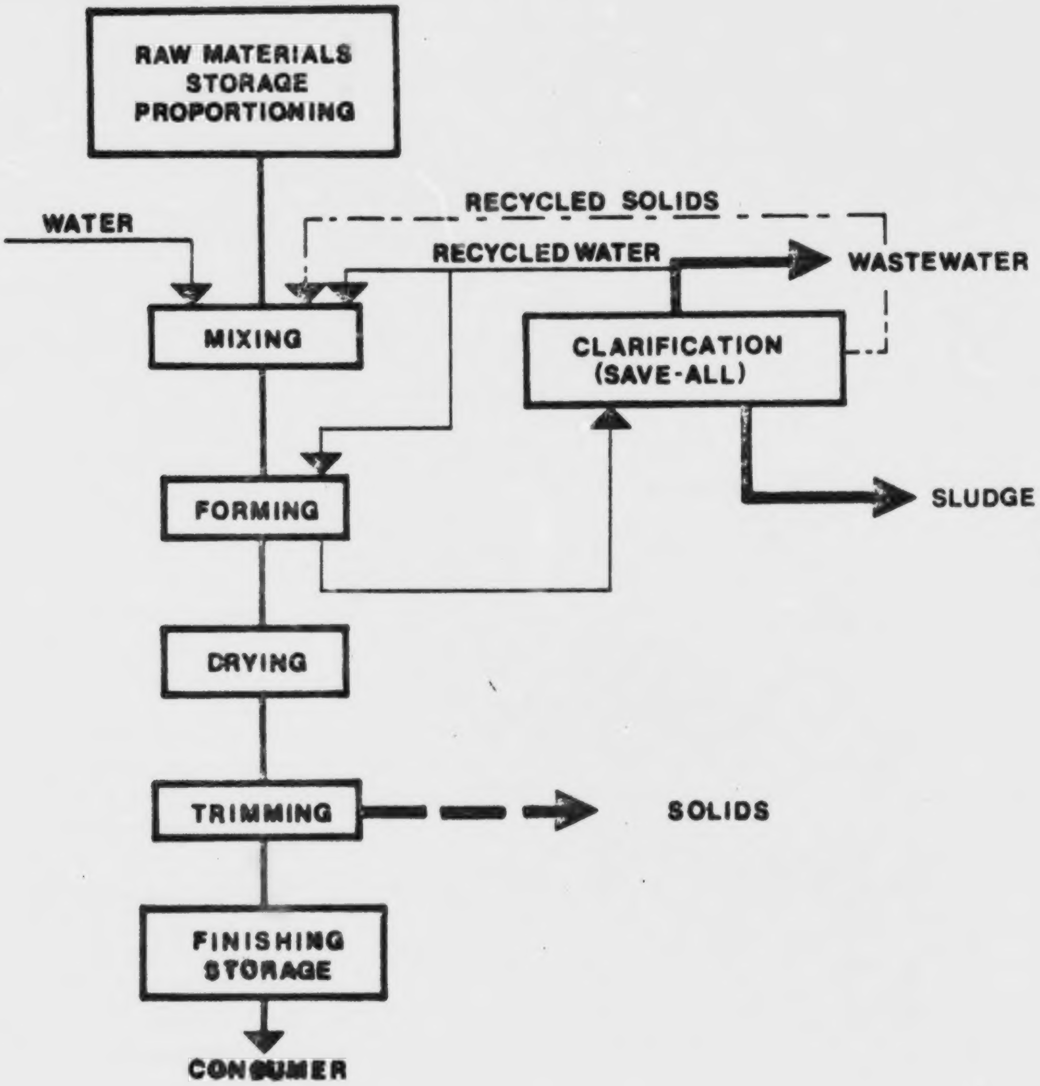

RAW MATERIALS
STORAGE
PROPORTIONING
WATER
RECYCLED SOLIDS
RECYCLED WATER
WASTEWATER
MIXING
CLARIFICATION
(SAVE-ALL)
FORMING
SLUDGE
DRYING
TRIMMING
SOLIDS
FINISHING
STORAGE
CONSUMER

Figure 12.1. Asbestos Millboard Manufacturing Operations (Carton, 1974)

in layers. This can be fixed to the surface with wire, bands, or sheathing. Fabric covering can also be applied with or without coating or paints. For furnaces, boilers, turbines, reactors, kettles, or other heated vessels, the asbestos millboard is attached to the surfaces by studs, bolts, bands, expanded mesh, or sheet metal. Dry asbestos fines are mixed into paste with water and adhesives for hand trowel or spray application to fill joints between the millboard sheets. The outside surface is finished by coating with cement, plastic, or fabric. The field installation may involve trimming, sawing, drilling, and grinding to fit the insulation material to the equipment. With the phasing out of factory preformed materials, all installations of asbestos insulation are currently following field fabrication procedures (EPA, 1974).

For electrical insulation, adapting factory formed asbestos material such as paper, roving, tape, or batting to the electric equipment in the multitude of electric manufacturing shops may be considered as field fabrication for installed asbestos material. These electric shop operations primarily include the following (Swiss, 1966):

Motor and transformer winding - The asbestos material in these applications is imbedded into the armature or core coil slots, either manually or mechanically, to give ground or conductor insulation. The operation involves handling dry friable material and consists in separating, inserting, cutting, and forming the asbestos fibers received as strands, braids, or roving in and around conductors. Asbestos insulation is especially useful for applications where the electric equipment is exposed to higher ambient temperature. This application is no longer used by manufacturers of large equipment. It is possible that it is used to a small extent by small specialty shops.

Conductor covering - Dry asbestos threads are braided onto conductor wires or cables, or batting impregnated with plastic is pressed onto and around the wire. These applications are used especially for services where high temperature occur. This is visualized as the principal remaining use of asbestos for electrical insulation.

Molded insulation parts - Although not primarily used for insulation purposes, asbestos is added to plastic and ceramic mixes to strengthen molded electric accessory parts, such as switches, connectors, and terminal bases and boxes. The asbestos fiber is mixed with the plastic or ceramic composition, fed to molds, and cured. The parts may require grinding, machining, or drilling.

The escape of dry asbestos fiber in the above operations into working areas is controllable by hooding and adequate ventilation. Bag filters or other separators are used to collect the fibers that may be released. These operations may occur at any of the many manufacturers of specialty machines and parts.

12.3 Asbestos Released to the Environment During Manufacture

Considering manufacture again in two categories, factory and field fabrication, release of asbestos during production and installation (emission control techniques are described in EPA (1973) publication) can be outlined as follows for each:

Factory fabrication - Under the current situation, where preformed insulating materials that contain asbestos are no longer produced, asbestos release in the factory operations chargeable to the manufacture of insulation products will be a fraction of that resulting from the larger production of paper and millboard sheet for the wider uses of these prime materials. The asbestos released in the manufacture of roving or braid type material for electrical insulation will similarly be a fraction of the total from production of these materials.

For paper and millboard, the releases will be prorated fractions of the quantity approximated for paper in Section 4.3. For the roving and braid materials, a similar approximation will be made. For the millboard operation, the release will be approximately the same as for paper per unit product. Also, it is assumed that all the thermal insulation or 6600 tons will be paper and millboard sheet. The releases consequential to thermal insulation would therefore be 3.5% of the release for roofing paper at its output of 85% of 215,000 tons per year (Table 9.3, Section 9.3.7). These releases apply to wasted scrap, to losses in air emission, and to waste water. These are shown in Table 12.4. Recovered dust from bag filters is approximated also at 3.5% of the roofing quantity or about 30 tons/year.

No data is on hand for the releases from the roving or braiding operation for the electrical insulation. Releases would, however, occur in grading, carding, combing, and treating the dry fiber. It is judged that the losses as scrap would follow paper manufacturing. The loss would be negligible since scrap would be recoverable as pulp for paper or board. Losses from the ventilation system would be larger than for paper because of the number of operations involved. The emission from the bag filters is therefore justified to be higher than for paper, as indicated in Table 12.4. There would be no waste water loss.

Releases of asbestos from the many and differing sites for field fabrication are even more indefinite. It is judged, however, that the releases

Table 12.4. Environmental Release of Asbestos from the Manufacture and Installation of Insulating Materials (SRC estimates approximated from 1976 consumption)

Point of Release	Annual Release (short tons)
I. In Factory Fabrication	
A. Thermal Insulation	
Scrap to waste	negligible[a]
Wastewater solids to waste	70
Wastewater effluents	1.0-3.0
Air emissions from bag filters	<0.1
Baghouse collections	30
B. Electrical Insulation (Rovings and Spinnings)	
Scrap to waste	negligible[a]
Air emissions from bag filters	<0.2
Baghouse collections	20
II. From Site Fabrication and Installation	
A. Thermal Insulation	
As scrap, all materials	50-100[b]
By air emission	
with dust collection	<0.1
without dust collection	30
B. Electrical Insulation	
Scrap to waste	15-20
In air emissions from filters	<0.1

(a) Based on nearly complete recycle.

(b) Includes contingency for spills, floor washing, etc.

that would result from fitting, trimming, forming the materials, and finally in pointing-up joints with asbestos-containing plasters, would be in the order of 0.5% to 1.0% of the installed materials as scrap to waste. Water losses would not occur. For field installation, it is probable that eventually portable bags for dust collection with portable hoods and ventilating system may be used for the larger installations. Releases without these provisions are excessive and are under scrutiny by EPA (EPA, 1974). Although the releases at any location may not be significant, the exposure to the installation contractor's personnel is continuous and high. The air emission released during field fabrication and installation is shown in Table 12.4 for both cases, i.e., with and without portable ventilating and dust collecting equipment. Recycling the dust collected by the filters may not be feasible under field conditions and no reduction in releases is obtainable; however, better control of the loss should be beneficial.

Table 12.4 indicates that in the field fabricated operations, release of material is more than in the factory operations. This approximation reflects inability to recycle scrap and also the poorer, if any, ventilation and dust collecting systems. As indicated above and by EPA (1974), the use of asbestos insulation material for field fabrication may also be phased out eventually.

The fate of the released asbestos to the environment as approximated in Table 12.4 will vary with local conditions. Typical cases are conceived as follows:

Scrap waste - From factory operation, scrap and other waste from the insulation production will be a small fraction of larger operations. These wastes, if any, are normally transported and deposited under plant control with provision to protect the public and will follow OSHA regulations for waste disposal (Anon., 1976). For field installation, scrap is usually picked up with trash collecting systems for disposal in public dumps or for landfill. Special control of friable dust losses is seldom used during transportation or unloading or in providing protection at the dump.

In the dump or landfill, the asbestos waste will become less of a concern in the buried locations where it is left.

In waste water - The asbestos content in the waste water is transported with the outflow into neighboring streams, lakes, or ponds until velocity drops and the solids deposited in stable shoals or beds, such as in Section 9.3 and other sections.

Airborne losses - The asbestos dust as initially emitted to the atmosphere will follow the prevailing wind, eventually settling on the ground and exposed surfaces. It will finally be washed away with rain or melting snow into streams along the same course as the waterborne material.

Disposal of asbestos waste by some form of incineration may release asbestos fibers into the atmosphere. Carlin (1977) has estimated that of the asbestos products disposed to municipal dumps or landfills, approximately 9% is destined for incineration. Carlin (1977) additionally estimated that incineration of all types of asbestos products annually emits about 220 short tons of free-fibers from all municipal incinerators; this estimate is based upon many assumptions and the accuracy is not certain. However, asbestos fiber releases from incineration may be a contributing factor to urban monitoring of airborne asbestos. Fibers could conceivably be lost in flue gases and in handling of cinders. However, at the current low production level of asbestos insulation materials, the fraction of the total loss attributive to this operation would be very small - say less than 5-10 tons/year.

12.4 Asbestos Released to the Environment from Installed Insulation

The intitial condition of installed asbestos is generally preserved with little deterioration over its considerable service life. Loss in strength of the asbestos occurs only where temperature may have been excessive. Other additions to the insulation mixture, however, may deteriorate by wear or accident. Also, maintenance, replacements, and renovation may be required before the equipment finally must be removed. The above conditions apply to the existing insulation for equipment and structures which were installed before current restrictions were involved, and specifically when asbestos insulation consumption averaged about 25,000 tons per year.

To approximate the releases that currently prevail under these present conditions, the following annual rates of disposition have been derived from the following economic pattern in terms of the total installed material:

Disposition of material required for:		% per year
Maintenance and repairs	=	2 (a)
Equipment replacement	=	4 (b)
Structural demolition	=	2.5 (c)

(a) Based on total labor and material at 5% per year with 40% material
(b) Based on average life at 25 years
(c) Based on average life at 40 years

In addition, the overall rate of growth is taken at 1.5% per year, and the division between process equipment and structurally dependent material at 75% and 25%, respectively. This distributuion is approximated from 1972 Census of Manufacturers data for mineral wool insulation (SIC Code 3296), which excludes asbestos insulation. These average 58% for equipment insulation and

42% for structural insulation. It is judged that because of the special requirements for asbestos, at least 75% would be used for equipment in the case of asbestos.

On the above basis, if T = total presently installed asbestos insulation, the rates of use would be related as follows:

$$.75\ (.02T + .04T) + .25 \times .025T + .015T = 25{,}000$$

$$\text{or installed material } T = 380{,}000 \text{ tons}$$

and from which the annual disposition of the installed asbestos amounts to the following:

For maintanenance and repair = 5700 tons/year
For equipment replacement = 11,400 tons/year
For demolition of structure = 2400 tons/year

Total replacement = 19,400 tons/year

On the basis of the above distribution of installed asbestos insulation, the fate of each category is visualized as follows:

In cases of maintenance and repair work, the removed insulation will usually be scrapped at numerous locations around the country and removed by usual waste collecting systems and deposited in landfill or trash dumps. The eventual fate would be similar to site fabricated waste (Section 12.3). It is judged that about 50% of the above equipment replacement materials would follow the same pattern.

For the remaining material replaced for renovation of larger equipment installations and for structural demolition, the controls required by OSHA (Anon., 1976b) and EPA (EPA, 1974) may be followed. These provisions required advanced notice before demolition or removal; separate removal of the asbestos insulation and wetting with water during removal and transporting. For these cases, the trend is to increase the precaution in handling the scrap, such as bagging and transporting and handling under controlled conditions to avoid dust and accidental exposures (Anon., 1976b). The restricted conditions applied especially where the scrapped material releases friable fibers. Limitations are not applied if asbestos is non-friable. "Friable asbestos material" is defined by EPA as "any materials containing more than 1% asbestos by weight and that can be crumbled, pulverized, or reduced to powder (when dry) by hand pressure" (EPA, 1974). The foregoing restrictions apply directly to enforcement of work practice standards for working conditions under OSHA control. These restrictions had not been formerly applicable to environmental emission control by EPA as a result of a court ruling dismissing a case against Adamo Wrecking Co. in January 1978. The dismissal was on the basis that work practice standards were not applicable for alleged emission violations by EPA. Presently, the Clean Air Act Amendments of 1977 (Anon., 1978) does permit work practice limitations to be used as a standard for emission control where other methods of measurement are not applicable. It is expected that a further modification for enforcement of the regulation will follow. The effect of the changes are not certain, however. Some greater amount of airborne asbestos contamination may result, limited, however, by OSHA restrictions (Anon., 1976b).

In summary of the above, it is seen that disposal through repairs, replacement, and demolition will involve approximately 20,000 tons per year of discarded asbestos insulation. This is currently the major release of asbestos insulation products to the environment. It will fade out as the presently installed materials are replaced with asbestos-free insulation. However, the disposition will be near the above rate for about 15-20 years. It is judged that approximately 60% of the quantity will be discarded through usual, uncontrolled municipal trash collecting systems. Only about 40% will be removed under controlled demolition systems as currently regulated. Guidelines for controls are outlined in EPA (1978) publication.

12.5 Alternative Materials to Asbestos for Insulation

Asbestos insulation, which is used principally for its heat resisting properties, can be replaced by fiberglass with or without calcium silicate for the lower range of temperature conditions, or up to about 1000°F, and by mineral wool with refracting ceramic fibers over higher ranges. The non-deteriorating property of asbestos is also obtained with these materials; the higher strength of asbestos fiber is not obtained. High strength, however, is not usually a critical requirement for insulation.

The prices of the asbestos insulating products range from 50¢ to $1 per lb. Alternate materials are obtainable with no economic disadvantage with respect to price or insulation value. For example, comparisons of price factors and insulation values, reciprocal of conductance, for asbestos millboard and for asbestos paper with fiberglass board and with mineral wool are presented in Table 12.5.

The low conductance gives fiberglass and mineral wool appreciably better insulating value than asbestos on both weight and surface area bases. Lower densities give these materials further economic advantage over asbestos. This advantage with the health consideration explains the continuing decrease in asbestos for insulating purposes.

Table 12.5. Comparison of Asbestos with Other Insulating Material
(Basis = 1 square foot and 1 inch thick insulation)

	Thickness per ply	Number of plies	Weight per sq. ft. (lb.)	K Factor[a]	Prices[b]		Maximum temperature (°F)
					Per lb.	Per ft.^{2}	
Asbestos							
Millboard	1/2"	2	4.6	1	$0.46	$2.10	1800
Paper	1/16"	16	5.0	1	$0.32	$2.60	1200
Fiber Glass	1"	1	0.25	0.36	$0.56	$0.14	1000
Mineral Wool	1"	1	1.1	0.44	$0.68	$0.75	1900

(a) K = BTU/hr/°F/inch/ft.^{2}

(b) Price and other information from suppliers' district offices.

13.0 PACKING AND GASKETS

Asbestos fiber used in 1976 for packing and gasket products amounted to 2.8% of the total U.S. consumption of the mineral. The 1976 consumption, 20,100 tons (Clifton, 1977), decreased about 25% from a consistent level near 25,000 tons per year for the 10 year period before 1974, shown by Table 4.9. The drop was partly due to use of substitute materials since 1974 to lessen exposure to asbestos and its health hazards (EPA, 1974). Increasing uses of newly developed products also reduced consumption (Jewitt, 1977).

As in the case of insulation, the removal of installed packing and gasket materials in the maintenance, removal, and demolition of container equipment will generate the principal release of asbestos into the environment. In most cases, the asbestos is not in free-fiber form due to impregnations or coverings that encase the fibers. Asbestos has been used for packing and gaskets for many years. Consumption is expected to continue near current level due to the advantages of the fiber compared to substitutes and because the hazardous fiber form of the material is not employed.

13.1 Asbestos Packing And Gasket Products, Uses And Economic Factors

Asbestos fiber is used in packing and gasket products because of its physical properties and comparatively low cost. The principal physical advantages are the strength and resilience, especially under compression, and the suitability to high temperatures and to a wide range of corrosive conditions. It is also adaptable to spinning into yarn and textile materials.

The asbestos materials are used in many forms and compositions for packing and gasket products. Commercial grades of asbestos starting with the fiber, sheet, or yarn are fabricated into compressed sheet, into beater impregnated sheet, and into impregnated millboard and yarn. The products may be sheathed in metal, plastic, or cloth, or reinforced with wire insertions. The products may be factory preformed or molded into desired shapes or field cut and fitted from the sheet, millboard, yarn, or molded compositions.

Although the above prime products are made by 22 principal fabricators (Table 13.1), much of the material is packaged and resold by a large number of small specialty companies. The 1975 Thomas Register lists about 200 companies under subsections covering asbestos gasket and packing suppliers.

For static applications, the gaskets provided as above are installed to obtain tight non-leaking connections for piping and other joints, such as at the covers and openings on all types of industrial and commercial equipment. For dynamic applications, packing is provided as a form of bearing for revolving or moving parts in stationary supporting members that also prevents leakage of the contained fluid along the bearing surface. The packing, usually in the form of rings of the material, is held by pressure against the moving part. Lubrication required at the separatory surface is provided by external or impregnated lubricants.

A breakdown of the grades and types of asbestos used in 1976 for gaskets and packing products is given in Table 13.2.

Table 13.2 Distribution of Asbestos Mineral Used For Packing and Gaskets (Clifton, 1977) (short tons)

Mineral Form and Grade Chrysotile	
Group 3	1,800
4	5,900
5	8,300
6	700
7	3,300
Total	20,000
Crocidolite	100
TOTAL	20,100

Table 13.1. Major U.S. Manufacturers Of Asbestos Gaskets, Packings (Margolin and Igwe, 1975).

FIRM	LOCATION
Raybestos-Manhattan, Inc.	Stratford, Conn.
Nicolet Industries	Ambler, Pa.
Johns-Manville Corp.	Manville, N.J.
Garlock, Inc.	Palmyra, N.Y.
Felt Products Mfg. Co.	Skokie, Ill.
McCord Corp.	Wyandotte, Mich.
Amatex Corp.	Norristown, Pa.
Gatke Corp.	Chicago, Ill.
Anchor Packing Co.	Philadelphia, Pa.
Vellumoid Division	Worcester, Mass.
Green, Tweed	N. Wales, Pa.
Crane Packing	Morton Grove, Ill.
F. D. Farnum	Lyons, Ill.
Sterling Packing & Gasket Co.	Houston, Tex.
Detroit Gasket & Mfg. Co.	Detroit, Mich.
A. W. Chesterton	Everett, Mass.
Hercules Div. of Richardson Corp.	Alden, N.Y.
Braiding & Packing Works of America	Brooklyn, N.Y.
Sacomo Packing Co.	San Francisco, Calif.
Sepco	Birmingham, Ala.
Quality Gasket & Mfg. Co.	Clawson, Mich.
Armstrong Cork Co.	Braintree, Mass.

As indicated, group 4 and 5 are used for 70% of the products, principally as fiber and woven materials. Imported milled fiber is the principal raw material (Table 3.1).

The shipment values of asbestos packing and gaskets are shown in Table 13.3. It is estimated that gaskets consume 66% of the raw asbestos fiber in the gasket and packing classification, or asbestos consumption for gaskets is roughly twice that for packing.

The shipment value of all types of gasket and packing products in 1976 is estimated to be roughly $900 million. The total value of asbestos gasket and packing products in 1976 is estimated at $70 million in Table 13.3, or roughly 8% of all these products. The tabulated approximation value of the asbestos products (about 8% of the total classification) is considered too low by manufacturers of these materials. An estimate that the current value of shipment was $250 million per year, or 25% of the total classification, was given (Jewitt, 1977). The reason for the difference is believed to be due to the mark-up on prices by vendors of specialty products, which Census data do not reflect.

13.2 Manufacturing Technology

The manufacture of gaskets and packing asbestos products may be considered under two classifications; namely, materials for static purposes, such as gaskets for pipe joints, and products for dynamic uses, such as pump and piston shaft packing (Fisher, 1967).

13.2.1 Gaskets

Most gasket materials are either compressed or beater saturated sheets. Compressed sheet is made from a plastic mixture of fiber, an elastomeric binder and a solvent. The mixture feeds a sheeting machine in which there

Table 13.3. Shipment Values of Asbestos Gaskets and Packing
(U.S. Bureau of the Census, 1972; SRC estimates)

SIC Product Code	Gaskets:	1976 Value	1974 Value	1972 Value	1967 Value
		Total Product Shipments, Including Interplant Transfer (All values in millions of dollars)			
32932 13	Compressed Asbestos	35*	50*	24.5	62.1
32932 15	Beater Saturated Asbestos			19.2	
32932 17	Asbestos Cloth			2.4	
32933 00	Packing and Miscellaneous	35*	50*	50**	———
	TOTAL VALUE ALL PRODUCTS	70	100	96.1	

* Adjusted for inflation and reduced production; also, approximated from Census Value on basis that price of packing is equal to twice price of gasketing on poundage basis.

** Approximated from SIC 32933-71 plus 32933-00 with allowance for the total estimate by Asbestos Information Assoc./NA @ $99.5 million for 1971 (Margolin and Igwe, 1975).

are two steel horizontal revolving cylinders, placed with close clearance. The smaller cylinder or roll presses the mixture onto the larger roll as it is slowly separated from the larger roll. The larger roll is heated to drive off the solvent and to compact the sheet. The large roll, about 40" diameter by 130" length, produces a sheet 120 inches square. The product contains about 20% binder such as rubber, chloroprene, or any special material that may be required.

The beater saturated sheet is made in a paper machine. The binder is added to the asbestos pulp in the beater as it feeds the machine. More elastomeric binder is used than in the above calender type compressed product. The product is used for less severe services than the compressed sheet.

Asbestos millboard sheet as selfbonded fiber, with practically all mineral and with little binder, is used for highest temperature services. The construction has less strength so it requires good support or supporting reinforcement.

Asbestos paper with wire reinforcing as well as impregnated woven asbestos is also fabricated into gaskets for special services.

White (chrysotile) and blue (crocidolite) asbestos are used up to about 900°F. Blue asbestos is used preferably to white for strong mineral acids and alkalis. The fabrics are graded from commercial grade at 75-80% asbestos for temperatures of 400°F to AAAA grade at 99-100% asbestos for temperatures of 900°F (Table 14.1 and Figure 14.2).

13.2.2 Dynamic Packing

Dynamic packing requires shaping, either by molding, machining, or forming the product with a non-abrasive material, to minimize wear at the contact with the moving part. Lubrication is also required. This can be impregnated into the packing or added separately. For these products, the asbestos yarn or braided material is impregnated with the lubricating additive, either in preparation or in molding. The required forms are obtained by pressing into desired cross sections. The formed product may then be coated with graphite or other materials. Also, fiber or yarn may be used as reinforcement to elastomers, such as rubber, and molded to desired cross sectional shapes.

13.3 Asbestos Released To The Environment During Manufacture

The release of asbestos during manufacture will be considered separately for the fabrication of the prime materials produced by the 22 manufacturers listed in Table 13.1 and for the larger number of vendors who may reform, package, or resell the prime materials as specialty products. Emission control techniques are given fully in EPA (1973) publication.

In the manufacture of the prime materials for gaskets and packing, such as millboard and yarn, the release contributed by the production of these materials will be a fraction of that caused by the production of the larger total operations that would be involved. There will be added to these approximations releases due to solvent recovery required for the impregnating operations.

The following separate manufacturing operations are involved and are considered in approximating the releases to the environment:

Compressed sheet gaskets production
Beater impregnated gaskets production
Impregnating millboard operation
Impregnating yarn operation
Molded products

For release as scrap to waste, it is judged that the amount would be between 0.5 and 1% of the total production. This would be largely as trimmings and cuttings. Because impregnated scrap cannot be recycled, full loss in this range is visualized and applicable to full production of 20,100 tons/yr.

Loss with waste water would apply to the impregnated beater saturated and millboard materials. It is approximated that these would have, on a unit production basis, the same loss as paper making (Table 9.3). Assuming that over one-third of the production falls in these classifications, as judged by Bureau of Census figures (Section 13.1), or at 8,000 tons/yr, the loss would be about 4% of Table 9.3 figures, or between 2 and 4 tons/yr.

Emission from baghouse filters is expected to follow approximately the same unit production release as paper making. Therefore, at 20,100 tons/yr for all above operations, the release would be 10% of Table 9.3 figures or less than 0.1 ton/yr. In addition to the air filter emission, emission from the solvent recovery operations is reported to be between .09-.18 lb/1000 lbs of the finished product (Margolin and Igwe, 1975). This would total for all products 10 to 20 tons/year.

The above approximations are summarized in Table 13.4.

The release of asbestos to the environment from the many distributors and rehandlers of packing and gasket materials is difficult to judge. If it is assumed to be essentially all as scrap from cutting and reforming, it might be conservatively in the order of 0.5 to 1%, or 10 to 20 tons/yr. The loss applies to full consumption to cover similar losses from material used directly at site. No significant loss of airborne material is visualized because the asbestos is encased for nearly all products by elastomers, plastics, graphite, or lubricants.

The fate of the released asbestos shown by Table 13.4 is visualized to be the same as conceived for insulation materials (Section 12.3). Again, scrap

Table 13.4. Environmental Release of Asbestos from Manufacture of Gasket and Packing Materials (SRC Estimates)

Point of Release	Annual Release (short tons)
I. In Factory Fabrication	
scrap to waste	10-20
wastewater solids to waste	100
wastewater effluents	2-4
air emissions from bag filters	<0.1
baghouse collections	35
emissions from solvent recovery	10-20
II. From Specialty Distributors and Field Installations	
as scrap to waste	10-20

from the factories would usually be deposited in landfill locations with protective provisions. The scrap from the specialty distribution is usually collected by public trash handlers with less care. Also, losses with waste water would be carried away by existing streams or flows. In nearly all cases, however, it is visualized that material would be encased with stabilizing additives and would not be susceptible to becoming airborne.

13.4 Asbestos Released To Environment After Installation

Asbestos gaskets are subject to wear only where used for frequently opened covers, manholes, and doors. The main uses of asbestos gaskets for pipe flanges and other permanently fixed positions only require replacement for maintenance, process revisions, or long-term equipment replacements.

Asbestos packing used essentially for dynamic services is subject to direct wear against the rotary shaft, piston, or moving part. A small fraction of the material will be released with lubricant leakage or into the contained mediums. The major release will be when the packing is scrapped during periodical replacement. It is judged that 90% of the packing consumed annually will be released in the form of worn out material.

In accordance with above conditions, the annual releases of asbestos are approximated for installed uses as follows:

For Gasket Materials, at 2/3 total consumption
    25% has less than 1 year life
    60% is for maintenance and long time replacement*
    15% is for new installation.

For Packing Materials, at 1/3 total consumption
    10% as immediate wear
    90% at annual life of 1 year or less

*Annual consumption is taken at earlier rate of 25,000 tons/yr for replacement losses.

For Gaskets	Tons/year
Short life uses = 20,100 x 2/3 x .25	3,300
Maintenance replacement = 25,000 x 2/3 x .60	10,000
For Packing	
As immediate wear = 20,100 x 1/3 x .10	700
As wastes scrap = 20,100 x 1/3 x .90	6,000
Total Release	20,000

Above approximate current release is based partly on former annual consumption approximating 25,000 tons. The release will drop slightly from above as release becomes consistent with lower current consumption.

The fate of the material follows about the same as concluded for insulation in Section 12.4. About 50% of the above is scrapped without special precautions and is removed by usual trash hauling facilities to waste dumps or landfill operations. It is visualized that the other half is handled in accordance with EPA restrictions as outlined in Section 12.4.

13.5 Alternative Materials To Asbestos For Gaskets And Packing

No completely satisfactory substitute for asbestos in gasket and packing applications is known. The combination of high strength and resiliency under compression, as well as resistance to high temperature and to a wide range of acid-alkali conditions makes asbestos unique at a comparatively low price range for the products. For example, fiberglas and mineral wool do not have the strength of resilience; organic and elastic fibers do not have temperature and chemical resistance. Teflon and graphite carbon compositions are at least five times the price.

Substitution has been possible only for lower temperature, low pressures, and non-corrosive conditions.

For packing and gasket applications, the asbestos fiber is encased in binding additives. It is therefore not readily airborne and is non-fibrous since it is contained in a matrix.

As a consequence of the above factors, it is visualized that little further replacement will occur and consumption will continue at near or above present rate.

14.0 TEXTILES

Textile products amounted to only 1% of all U.S. asbestos uses in 1976. The annual uses for textiles, 7,400 tons, as reported by the Bureau of Mines for 1976, dropped more than 50% from the 10 year level of over 15,000 tons (Table 4.9) (Clifton, 1977). The decreased use resulted from limitations imposed by health control hazards (Anon., 1976b). Glass fiber was the principal substitute material.

End use textiles, classified as above, are estimated to be roughly less than one-third of all manufactured asbestos textile materials. The latter include intermediate products used for other classifications such as friction, insulation, and gasket products (Sections 6, 12, and 13).

It is believed that the use of end use textiles may have leveled off and may slowly rise as more dust-free materials and processes develop, and assuming controls do not become more restrictive.

Textile products have generally short life applications. Release to environment therefore averages near consumption level, principally as worn out scrap to waste dumps. Nearly all the materials are impregnated or coated to suppress dust; hence, the potential for fibrous dust emission is low, except for occasional uncontrolled conditions.

14.1 Uses and Economic Factors

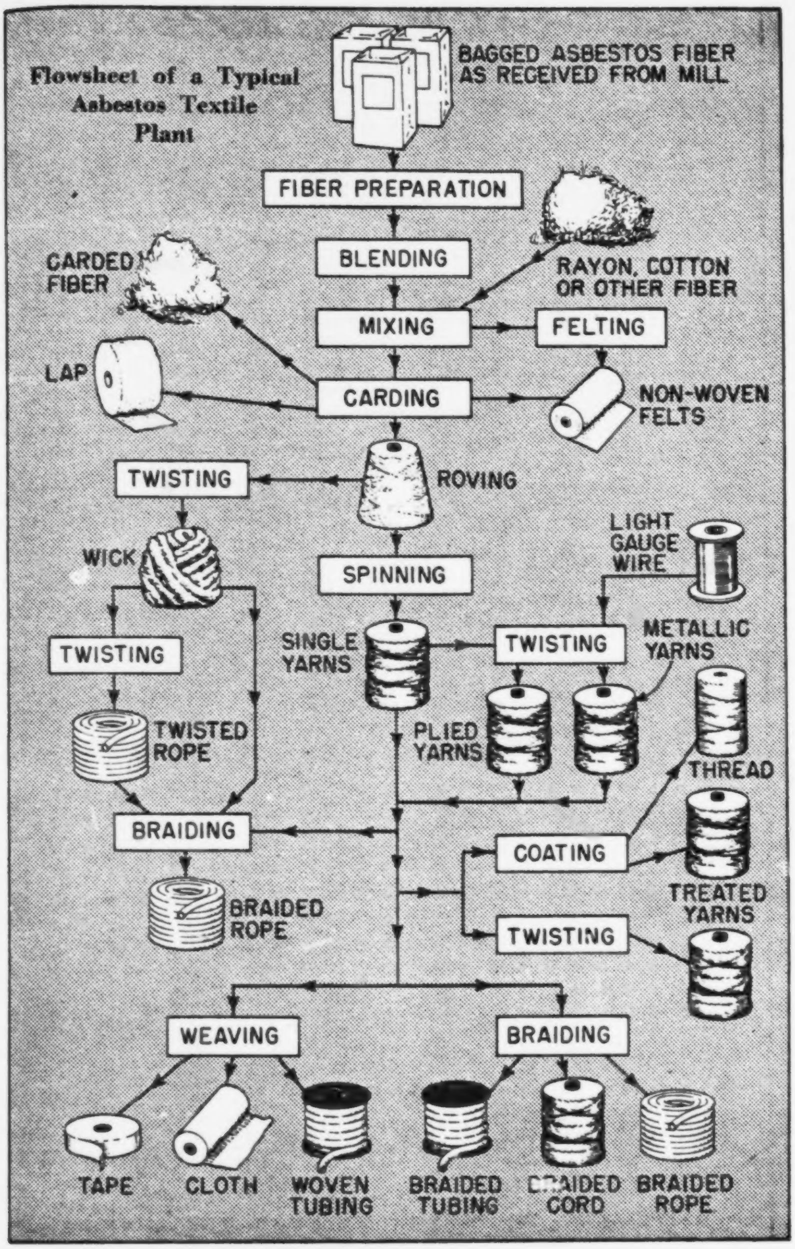
Asbestos has been known and used for textiles to resist fire and heat since ancient times. Modern commercial operations have been well established for more than 100 years. Chrysotile, as used for textiles, is stable up to 900°F and can be used for continuous operations up to 900°F; chrysotile can also be used in higher temperature applications, but only for interrupted periods of time (Anon., 1967). Fibers above 1/4 inch are readily spun into yarn, cord, thread, cloth, roving, rope, tape, braid, and corded fibers (Figure 14.1). These primary textile materials are fabricated into protective clothing, curtains, blankets, filters, diaphragms, and other articles where resistance to flame, fire, heat, and exceptional corrosion is required.

The above products are used industrially in welding, for furnace and other flame or high temperature operations, and for equipment such as conveyor belts for hot materials. Other uses include diaphragm fabric for electrolytic cells and lap and carded fiber for beverage filter media, although asbestos papers are more commonly used for these purposes. The above applications are exclusive of intermediate textile materials used for other products such as brake lining, electric insulation, and pump packing, as covered by Sections 6, 12 and 13.

The pure asbestos products, usually coated with acrylic or similar resins to suppress dusting, can also be reinforced with cotton and other fibers or with metal wire and sheaths. They can also be sprayed with aluminum to further reflect heat effects.

The strength retention of plain asbestos fibers for the several grades at elevated temperature is shown by Figure 14.2 and the asbestos content for the several grades by Table 14.1.

The distribution of asbestos fiber used for textile products with respect to grade and mineral is shown for 1976 by Table 14.2 (Clifton, 1977). All are in the longer grades as required for spinning.



Flowsheet of a Typical Asbestos Textile Plant
BAGGED ASBESTOS FIBER AS RECEIVED FROM MILL
FIBER PREPARATION
BLENDING
RAYON, COTTON OR OTHER FIBER
CARDED FIBER
MIXING
FELTING
LAP
CARDING
NON-WOVEN FELTS
TWISTING
ROVING
WICK
SPINNING
LIGHT GAUGE WIRE
TWISTING
SINGLE YARNS
TWISTING
METALLIC YARNS
TWISTED ROPE
PLIED YARNS
THREAD
BRAIDING
COATING
BRAIDED ROPE
TREATED YARNS
TWISTING
WEAVING
BRAIDING
TAPE
CLOTH
WOVEN TUBING
BRAIDED TUBING
BRAIDED CORD
BRAIDED ROPE

Figure 14.1 (Anon., 1967)

CHART A

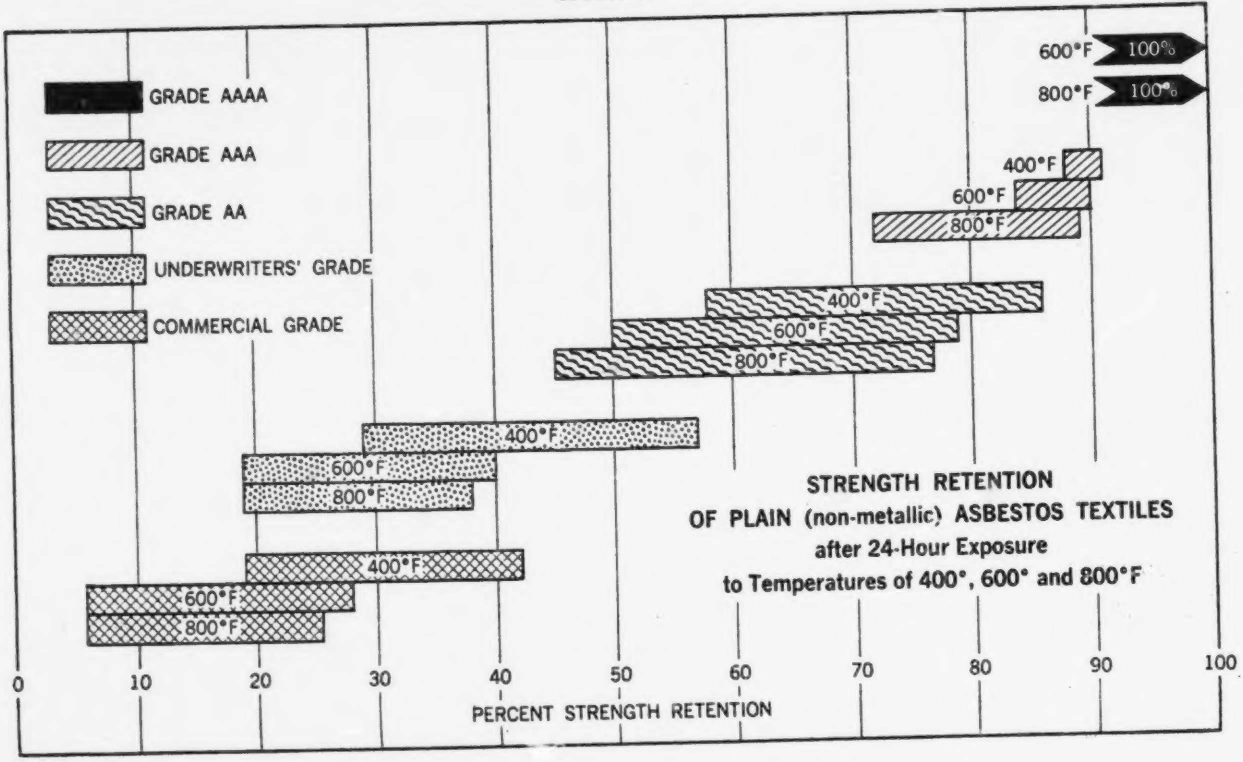


Figure 14.2 (Anon., 1967)

Table 14.1. Percentage of Asbestos Content by Weight in Asbestos Textile Products[1]

As Established by the American Society for Testing and Materials

GRADE	ASBESTOS CONTENT BY WEIGHT
Commercial	75% up to but not including 80%
Underwriters'	80% up to but not including 85%
Grade A	85% up to but not including 90%
Grade AA	90% up to but not including 95%
Grade AAA	95% up to but not including 99%
Grade AAAA	99% up to and including 100%

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[1] See ASTM Specification D 1918, page 92, for the test methods used to determine asbestos content (grades).

Table 14.2. Distribution of Asbestos by Grade and Type 1976 (Clifton, 1977)

	Tons
Chrysotile	
Group 1 & 2	200
3	6900
4	300
TOTAL	7400
Crocidolite, Amosite, Anthophylillite	none
TOTAL	7400

As with other products, about 90% of the milled fiber was imported from Canada. U.S. sources are shown in Table 5.1.

The prime textile materials used by the industry are produced in the following five plants in the U.S. (Fagan, 1977):

Firm	Location
Raybestos-Manhattan, Inc.	North Charleston, N.C. Marshville, N.C.
Southern Asbestos Co.	Charlotte, N.C.
Amatex Corporation	Meridith, N.H. Norristown, Pa.

An approximation of the present annual value of asbestos textiles is shown in Table 14.3, using 1972 Bureau of Census data and Bureau of Mines consumption figures. The values are approximations assuming average prices, such as cloth now averaging near \$3 per lb. and yarn near \$2 per lb.

The foregoing review applies only to the production of the primary asbestos textile materials, i.e., yarn, cord, and cloth. As in the case of gaskets and packing (Section 13), these prime materials are used by a larger group of distributors and fabricators that manufacture clothing articles and other specialties, as well as distribute the prime and treated prime products.

Table 14.3. Distribution of Quantity and Values of Textile Uses (U.S. Bureau of the Census, 1972)

SIC CODE		1967	1972	1974	1976
	PRODUCTION (Million lb)				
32927-11	Yarn, Cord & Thread	9.4	17.5		
32927-21	Cloth	10.2	11.1		
32927-31	Others	-	-		
	TOTAL	19.6	28.6	20.4 (a)	7.4 (a)
	VALUE (Million $)				
32927-11	Yarn, Cord & Thread	7.1	13.7		
32927-21	Cloth	12.3	15.1		
32927-31	Others	11.5	8.4		
	TOTAL	30.9	37.2	30± (b)	20± (b)

(a) From Bureau of Mines - Minerals Yearbook 1973 & 1977 for users
(b) Estimate - for 1974 at $1.50/lb
- for 1976 at $2.75/lb

Note: Bureau of Census figure for annual production runs about 40% above Bureau of Mines figures for uses, indicating an excess of exported over imported product. With imported textile asbestos in 1976 at $10 million (Fagan, 1977) a large value for exports is indicated.

It is judged that the rehandling and treating would raise the market value of current textile output manyfold.

A rough approximation of the fraction of textile end products, as classified in Table 14.3, is made from the data in Sections 6, 12, and 13 using 1976 figures for uses (Clifton, 1977):

Textiles Materials Used For,	Tons/yr
1. Brake lining @ say 15% of 64,000 (Sec. 6) =	9600
2. Insulation @ say 26% of 8,900 (Sec. 12) =	2300
3. Gaskets @ say 34% of 20,100 (Sec. 13) =	6900
TOTAL	18,800

$$\underline{\text{\% Textile end-products}} = \frac{7400}{18{,}800 + 7{,}400} = 28\%$$

of total textile material manufactured.

14.2 Manufacturing Technology

Asbestos textiles are sold in various forms, namely yarn, cord, thread, and cloth. Also, intermediate products such as roving, mat, braid, and tape are made in these operations.

Most asbestos textiles are spun from fiber by similar spinning operations as used in cotton and wool milling (Joseph, 1966). The successive steps are shown in Figure 14.3. It consists principally in grading and cleaning the fibers by air classification, carding and combing the fibers into a parallel arrangement as a mat, then separating the mat into strands that are wound into spindles to form roving. The roving is spun into yarn, twine, or cord on spinning frames. The yarn is woven into fabric, braid, or tape.

In addition to the established spinning process as covered in the foregoing, there are new wet processes which are based on forming single filmament fibers by extrusion. These processes, i.e., Raybestos-Manhattan, Novatex

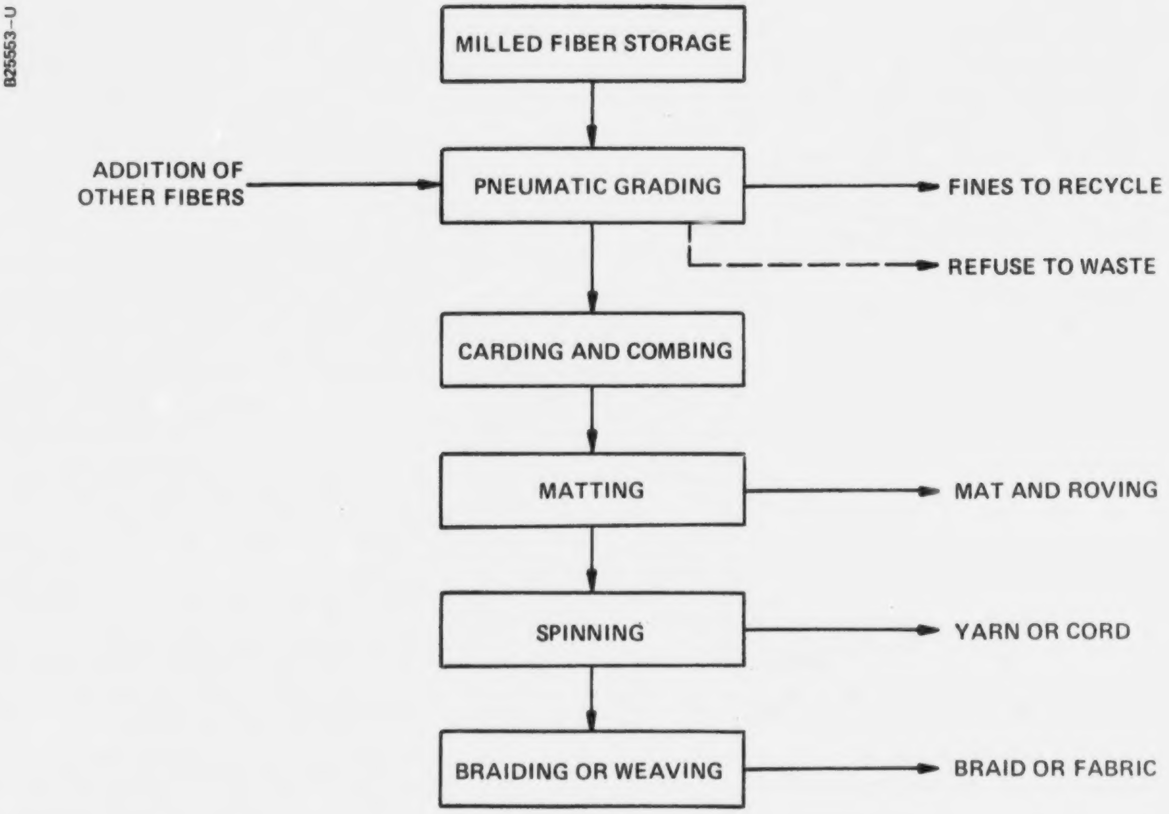
B25563-U
MILLED FIBER STORAGE
ADDITION OF OTHER FIBERS
PNEUMATIC GRADING
FINES TO RECYCLE
REFUSE TO WASTE
CARDING AND COMBING
MATTING
MAT AND ROVING
SPINNING
YARN OR CORD
BRAIDING OR WEAVING
BRAID OR FABRIC

Figure 14.3. Asbestos Textile Operation (Margolin and Igwe, 1975; Anon., 1967)

Process, and Turner and Newall Fortex textiles, represent only 5-10% of current production (Colson, 1977). With these processes the extruded thread is spun to the cord or cloth as with the fiber. The process consists of making a gelatinous mixture of fine asbestos fiber in water with a volatile dispersant. The mass is extruded through small dies. Threads as fine as 80 cut* are made (Colson, 1977).

To suppress dust (in handling and fabricating the above textile prime materials), coatings, principally acrylic resins, are applied to most of the cloth product. This treatment effectively controls dust release, permitting use within OSHA guidelines (Anon., 1976).

Relatively little water is used in textile manufacture. There is occasional washing of waste from coating operations (Margolin and Igwe, 1975).

The foregoing applies to the manufacture of the prime materials before fabrication into consumer end products. These consumer products are later tailored by many distributors into other forms and specialty products (Thomas Register, 1975). These involve varied types of operations as required for cutting, sewing, impregnating, recoating, molding, pressing, and reforming the prime materials.

14.3 Asbestos Release to the Environment from Textile Manufacture

Release of textile asbestos to the environment falls into two categories, namely release during manufacture of prime products (yarn, cord, and cloth) and release during fabrication of the prime materials into consumer products, clothing, fine curtains, and specialty products.

Releases of asbestos to the environment during manufacture of the prime textile materials arise from two sources, namely as the scrap to waste and as the emissions in the exit air from bag filters in the plant ventillating system. The present process has no significant waste water effluents. A small intermittent amount of wash water is wasted from the coating operation (Margolin and Igwe, 1975). Also, water is used in the new "wet" processes. The effluent from these is small and is discharged to city sewers. Wet scrubbers, formerly used for ventillating systems, are being replaced by bag filters (Margolin and Igwe, 1975). It is visualized that all the wastes may reach 5% or more of total production or roughly 500 tons/yr from the several producing plants. This would also include refuse and sweepings from the grading operation and plant.

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* 80-100 yard lengths per pound (Cooper, 1961)

The emission of asbestos in exit air from the bag filters in the plant ventillating systems is judged to be about twice the emission from the paper making operation for the roofing industry, per unit production, or about 10% of the approximation in Table 9.3, or a total of less than 0.2 ton per year.

The releases of asbestos to the environment during the handling and fabrication of the prime materials into specialty products will be essentially all as scrap to waste dumps. Some exception may occur when scrap is recycled to fabricators. It is visualized that scrap to waste may range between 1-2% as cutting, trimming, and sizing the prime materials into consumers' products, or approximately 75-150 tons per year from the many distributing and fabricating sites. The losses of airborne material are insignificant with current OSHA guide line controls in operation.

The above releases are summarized in Table 14.4.

The fates of the released asbestos as scrap to landfill or waste dumps will be the same as visualized for the insulation and packing products

Table 14.4. Approximation of Release of Asbestos to the Environment During Textile Manufacture

During Manufacture of Prime Products (a)	Tons per year
As scrap to waste	500 tons
In air emissions from plants	<0.2
In Fabricating Consumers Products (b)	
As scrap to waste	75-150 tons
As air emission	negligible
Total Release in Manufacture =	125-200 tons

(a) Approximation applies to the several plants listed in Section 14.1 or in order of 10-15 tons/plant/year.

(b) Approximation applies to the 50 or more distributing and specialty fabricators of between 0-5 tons/year/site.

(Sections 12 and 13). The asbestos will eventually become stabilized with the other waste materials in the deposits. As indicated, the approximated release is visualized not to exceed about 15 tons per year at any of the many landfill sites.

14.4 Release of Asbestos Textile Products to the Environment During Use

Textile products generally wear out at a comparatively fast rate. As a consequence, replacement is approximately equal to consumption, with the worn out material released as waste to municipal landfill dumps. With currently used coated materials, no significant quantity of the products is released to the atmosphere, and it is visualized that essentially all the material becomes waste or scrap. On this basis, about 7400 tons per year are scrapped and sent to landfill or other waste dumps. The annual release may be somewhat higher today due to a backlog from the larger use before 1974. This will soon stabilize nearer the current consumption level.

These losses, as worn out articles to waste dumps, represent the most significant release of asbestos to the environment from the textile sector. This source is widely spread over many dump sites. Also, this source is very small as compared with those for roofing and other asbestos uses.

14.5 Alternatives to Asbestos Textiles

There is no completely satisfactory substitute for asbestos for many textile uses. Although glass and mineral fibers are used as fairly good substitutes, neither has as good heat or corrosive resistant properties or as high strength. When combined with ceramic binders, application up to 5000°F is reported (Anon., 1967). Also, the prices of asbestos textiles are comparably low ($8-$10 per yard) or about the same as for glass. Plastics such as du Pont Nomex are considerably higher.

The dust suppression coatings that permit ready use of asbestos products within present OSHA guidelines should encourage contined use of asbestos textiles at near or above current level.

15.0 ASBESTOS COATING AND PAINT COMPOUNDS

Asbestos used for coating and paint compounds in the U.S. in 1976 amounted to nearly 20,000 tons, as classified in the Bureau of Mines Mineral Commodity Profile 1977 (Clifton, 1977). This consumption, which is approximately 3% of the total asbestos consumption, excludes the material used in coatings for roofing purposes (see Section 9). With roof coatings included, total consumption for all coatings was estimated by an industry survey to total 67,500 tons for 1975 (Daly *et al.*, 1976).

Neither Bureau of Mines nor Bureau of Census reports have data by which consumption trends for these products can be estimated. Discussions with suppliers and consumers of coating products give considerably different predictions with respect to future applications of asbestos in these materials. Some suppliers have abandoned use of asbestos entirely because of OSHA restrictions. Others continue to use asbestos at essentially the same or higher rates. In summary, it is judged that the reduction in uses to present level has been extensive but that the current level will probably be held. The latter results from accepted realization that in nearly all coating applications the asbestos is completely encapsulated. No injurious fibrous type dust is consequently released during uses of the products. Also, new uses and products, such as the short fiber California asbestos, are expected to have increasing applications (Anon., 1977).

15.1 Uses of Asbestos in Coatings, Paints, and Sealants

Asbestos fiber is used as a filler and reinforcement in asphalt and tar base coatings, paints, and sealants to improve the strength, corrosion and wear resistance, and other qualities of the products.

Filler materials, with reinforcing properties, modify the properties of the bituminous compounds (Endersby, 1948). Strength and stability of the products are improved. The effects of temperature on plastics are controlled. Resistance to weathering, oxidation, and other wear factors are increased. High fiber strength and other structural characteristics make asbestos fibers the most effective reinforcement with respect to these properties.

The asbestos content in bituminous coating mixtures ranges from 10-12%. The mixtures also contain about 50% volatile petroleum solvents. The bituplastic or bitumastic mixes are applied to the surfaces by brush, spray gun, roller, or trowel, depending on the concentration of the asbestos. Other ingredients are also used as required for service conditions. Pigments, rust proofing chemicals, heat reflecting metallic paints, and other fillers may be added. Additional insulation materials such as cork, emulsifiers, and resins are also used. The solvent evaporates after application, leaving a long wearing protection film or coating. Asbestos is especially effective in reducing the tendency of the binder to flow or crack with changes in temperature.

The above products are used in a wide variety of services (Anon., 1970). The largest use is for roofing applications, as included in Section 9. Otherwise, these coatings are used as sealants to moistureproof and waterproof concrete foundations, side walls, tanks, and structures such as cooling towers in nuclear power plants. The coatings are applied as light sealants or as heavier coatings, depending on the asbestos content and number of coats applied.

The products are used as protective coatings for underground pipe lines and for anti-condensation coatings for low temperature refrigeration services. They are used for corrosion resistance in exposures to sea water spray, salt solutions, organic or mineral acids, or petroleum products. Some automobile undercoatings use asbestos in the protective preparation, especially if sound deadening is also desired. The coatings are used for fireproofing structural steel. Aluminum or zinc is added to reflect the heat or to improve heat resistance properties. The products are applicable to primed metals, masonry, concrete, plaster, glass, wood, brick, and cinder blocks. Application of these coatings require adherence to amendments of the Clean Air Act of 1977 and guidelines described in EPA (1978) publication.

Bitumastic coatings with asbestos filler have been used for wood block and concrete floor mastics, tennis court coverings, chimney stack paints, and driveway seal coats. Asbestos is a constituent in some texture paints (Anon., 1976c).

Other resinous liquids are used to a smaller extent as vehicles for asbestos fillers for special coating applications, especially when controlled viscosity and thixotropic properties are required (Anon., 1977).

As indicated earlier, many suppliers of coatings and paints have stopped the use of asbestos as an additive, replacing it with fiber glass, talc, or other fillers. Other suppliers, however, continue to produce or distribute products containing asbestos.

The asbestos used as filler for coatings, paints, and sealants is principally made from the grade of mineral shown by Table 15.1. The shortest grades of chrysotile are used. Over 95% is in Group 7. As with other asbestos products, about 90% of the milled product is imported from Quebec.

Asbestos coatings, paints, and sealants are made by many suppliers. The Thomas Register (1975) lists 27 companies that sell asbestos paints. Also, about 100 suppliers of asphalt paint are listed that may add asbestos to their

Table 15.1. Distribution of Asbestos Minerals Used for Coatings, Paints, and Sealants (Clifton, 1977)

Mineral Form and Grade	Quantity (short tons)
Chrysotile	
Group 4	300
Group 5	300
Group 6	100
Group 7	19,200
Total	19,900
Crocidolite	---
Amosite	---
Anthophyllite	---
Total asbestos tons/year	19,900

products without being classified as asbestos paint vendors. Many in these groups mix the paints. Others only pack and resell the mixed products.

In addition to the above suppliers to the national market, it is judged that many small suppliers mix smaller quantities of asbestos coatings for limited local markets.

National manufacturers of asbestos texture paints, as identified by Anon. (1976c), include Mary Carter Industries (Tampa, Fla.), Bondex International (Brunswick, Oh.), and Synkoloid Co. (Atlanta, Ga.).

There is no census information on the value of the asbestos coatings and paint products being produced. The Bureau of Census reports do not separate this classification from asphalt and other base paints (SIC Codes 2851 and 2951). However, information developed from industry estimates gives the total use for all roof and other asbestos coatings as 67,500 tons in 1975 (Daly, 1976). This states that an expenditure for \$4.22 million per year would be 1.6% of total annual sales. On this basis, total sales in 1975 were about \$264 million. For the 20,000 tons reported by the Bureau of Mines for 1976, the prorated annual value of sales for coatings, paints, and sealants, other than roof products, would be:

$$\frac{20{,}000}{67{,}500} \times \$264 \times 10^6 = \$78 \text{ million}$$

and the value per ton on contained asbestos would be \$3750.

The above value, as well as the quantity for coatings and paints used in the above approximation, is high in relation to the value and quantity given for fibrated asphalt roof coatings by the 1972 Census of Manufacturers. The figures for this use, SIC Code 29522-51 (generally considered higher than the other coatings), were \$20.6 million for value and 44.2 million gallons. The latter would be less than 20,000 tons if 10% asbestos, or a value of \$1000 per ton of asbestos. To explain the inconsistency, it is believed that the Bureau of Census data covers only the use by identified major producers and excludes the large number of small suppliers of asphalt paints and coatings that use asbestos but are not classified as asbestos paint suppliers. The high comparative price value for the product appears to result from the much higher unit value for the products given by the industry. As in the case of other asbestos products, the explanation is probably due to use of retail prices in the industry estimate and lower production cost values that the Bureau of Census reports. On the basis of unit value used in the Bureau of Cenus report, the forgoing value of asbestos coatings and paints would be cut to about $20 million. This is about 15-20% of the Bureau of Census value for all industrial maintenance paints, SIC Codes 28516-11,13, of about $125 million in 1972.

15.2 Manufacturing Technology

The manufacture of coating and paint compounds consists simply of thoroughly mixing batchwise fine dry asbestos fiber with bituminous vehicles, such as asphalt and tar, along with a volatile solvent and other additives to give specific properties to the bitumastic product. The asbestos concentration ranges up to 10-12% in the product, depending on requirements for the application (also refer to Section 9.2).

The overall operation consists in charging asbestos as received in sealed bags into a storage-feeding system, measuring the asbestos into a batch mixing tank where it is thoroughly blended and impregnated by the bituminous solution. The product is discharged when finally mixed into metal containers for delivery to the market. The principal shipments are in 5-gallon sealed lid pails (Daly et al., 1976). Smaller size pails, as well as drum and tank car quantities, are also shipped.

The scale of the operations covers a wide range in annual capacities, up to about 3 million gallons, and in batch units up to several thousand gallons.

No waste process water is produced. The only water used is for washing purposes. Atmospheric contamination, which is potentially possible from the bag emptying step, is controlled by ventilation with dust collection bag filters. The collected dust is recycled to the feed. No scrap material is produced.

The production facilities for the coating, painting, and sealant products are the same as for roof coatings (Section 9), except that they are usually at a significantly lower market requirement (as previously discussed). Consequently, the coating operation will usually operate on a part-time basis with the roof coating products, as well as with other non-asbestos containing coatings.

15.3 Asbestos Released to the Environment During Manufacture

Release of asbestos to the environment during the manufacture of coating and paint compounds will normally be only that entrained with air emitted from bag filters. No significant scrap or water effluents are produced. The asbestos released from bag filter emission can be approximated as in Table 9.3, at a maximum of less than 1 ton per year, on average, for the entire coating and paint compound production operations. The dust from bag filters is the only release in which fibers are in free-fiber form. In other effluents from washing, floor spills, and in wastage of the bitumastic product, the asbestos fibers are encapsulated in the binder. Emission control techniques are outlined fully in EPA (1973) publication.

15.4 Asbestos Released to the Environment During Uses

Release of asbestos to the environment during use will occur from the following sources:

1) Wastes during application;
2) Losses from weathering, wear, corrosion, etc. in services;
3) Scrap from maintenance, replacement, and from final demolition of the structure or equipment.

In nearly all these losses the asbestos should be completely encased in the bituminous binder. As a consequence, only small quantities of free-fiber as airborne material are visualized.

One area of concern, in regards to release of free-fibers, is in removal of texture paints containing asbestos. Sanding asbestos texture paint to remove it from a wall may produce a serious health hazard (Anon., 1976d). Any coatings or paints containing asbestos which are subjected to sanding or similar physical forces will probably release free asbestos fibers which can be inhaled. In this particular category, textured paints are probably the only application in which removal by sanding is utilized; therefore, asbestos texture paints are likely to present the greatest potential for free-fiber releases in the coatings and paints classification. It should be noted that there is no available monitoring data by which to quantify free-fiber releases from coatings or paints.

It is possible that sales of asbestos texture paints may fall sharply due to adverse publicity resulting from school closures in New Jersey in early 1977. A junior high school pupil was diagnosed to be suffering from a respiratory illness caused by inhaling asbestos particles at a school which was recently painted with asbestos paints to improve acoustics; as a result, the school was closed to remove the asbestos (Anon., 1977b). It was later discovered that the pupil was not suffering from asbestos exposure. However, such publicity may certainly cause new buyers of texture paints to shy away from asbestos. Unfortunately, some brands of texture paints which contain asbestos do not list asbestos as an ingredient on the label (Anon., 1976c). Amended Air Control Act of 1977 and guidelines given by EPA (1978) publication cover regulations for these applications.

Considering the entire classification for coating and paint compounds, it is judged that an average of 1% of annual consumption is released as waste in spillage, washings, and scraps during application. Scraps left in container pails and some spillage are usually disposed to landfills, while some spillage and washings may be disposed to municipal or plant sewer systems, from which the asbestos particles would finally settle in deposits in the disposal system.

Losses of asbestos in service are judged from the usual maintenance and replacement rates for industrial equipment, as in Section 12.4, to be approximately 25% of the annual consumption. In the case of coating and paint compounds, it is visualized that the losses resulting from oxidation, cracking, and peeling of the bituminous binder are in large pieces that are flushed off by rain, spray, mechanical wear, corrosion, wear, or water condensate to floors, ground, and surroundings. These may be washed away by the above processes in ground water or spilled into process or municipal sewers or drainage systems. Hence, the material collects as deposits in settling areas in the system. On the above basis, the annual quantity from these sources is about 5000 tons per year.

The asbestos contained in coating and paint compounds that would usually be scrapped during replacements and demolition of the equipment and structure to which they are applied varies with the material. On steel equipment, structures, piping, and other metallic material, the fate of the coating is usually to scrap yards and recovery furnaces where the asbestos disappears as slag from the charge. On demolished concrete and other non-recoverable materials, the asbestos coatings are usually sent to landfill dumps or perhaps to incinerating operations. The fates of the material from these dispositions are covered in earlier sections. The total quantity of asbestos released as scrap approximates the balance of annual consumption after 1% reduction for losses in application, 1-2% consumed for expanding uses, and 25% in maintenance uses. This equals about 70% or 14,000 tons per year. As an approximation, it is roughly judged that 10,000 tons per year goes to landfill dumps and the balance (or 4000 tons) disappears in scrap recovery furnaces.

The above figures, which are summarized in Table 15.2, are based on the 1976 consumption demand. These do not allow for the backlog that may prevail from earlier consumption at higher rates. These past higher consumption rates will tend to increase the scrap rate for the near future.

15.5 Alternative Materials to Asbestos for Protective Coatings and Paints

The high strength, fineness, and structure of the asbestos fibers has made it nearly impossible to substitute asbestos with an equivalent filler for best quality coatings and paint compounds. As shown by Table 15.3, the tensile strength of asbestos is much higher than for fibers of other spinnable materials. Also, the fine fiber sizes and construction make asbestos unique in its property to obtain high viscosity and thixotropic quality in the applied coated film. These factors improve the life of the coatings with respect to weathering, with less cracking and peeling away of the coating, and better adherence to the protected surface.

Table 15.2. Approximation of Asbestos Released to Environment from Coating and Painting Compound Applications

Source	Disposition	Tons Per Year
Waste during application	To sewer system or landfills	200
Losses from wear, weathering, and service	To sewer system or ground waters	5,000
Scrap from replacement and demolition	To scrap metal recovery furnaces	4,000
	To landfill and incineration	10,000
	Total release	19,200

Note: Nearly all of the asbestos released in the above total is encapsulated in the binders and is not in free-fiber form. Section 9.4 gives a hypothetical example of fiber release from weathering effects, assuming the fibers are in a free-fiber state.

Table 15.3. Comparisons of Various Asbestos with Other Material (Clifton, 1975)

STRENGTH

Fiber	Tensile Strength		Young's Modulus		Specific Gravity
	Kg/cm^2	$Lb/in^2 \times 10^3$	Kg/cm^2	Lb/in^2	
Crocidolite	35,000	500	172.2×10^4	24.6×10^6	3.2
Amosite	21,000	300	153.3×10^4	21.9×10^6	3.1
Chrysotile	28,000	400	155.4×10^4	22.2×10^6	2.4
Glass	15,500	250	73.0×10^4	8.5×10^6	4.6
Aluminum	1,800	25.6	70.0×10^4	9.9×10^6	2.7
Steel 5137	3,700	52.6	190.0×10^4	27.0×10^6	7.8

FIBER SIZE* (Asbestos Textiles, 1975)

Type of Fiber	Fiber Diameter (inches)	Fibrils in One Linear Inch
Human Hair	0.00158	630
Ramie	0.000985	1,015
Wool	0.0008 to 0.0011	910 to 1,250
Cotton	0.0004	2,500
Rayon	0.0003	3,300
Nylon	0.0003	3,300
Glass	0.00026	3,840
Rock Wool	0.000142 to 0.000284	3,520 to 7,040
Asbestos (Chrysotile)	0.000000706 to 0.00000118	850,000 to 1,400,000

* Canadian Mining and Metallurgical Bulletin, April, 1951

SURFACE AREAS* (Asbestos Textiles, 1975)

Type of Fiber	Surface Area by N_2 Adsorption (sq. cm./gram)
Nylon	3,100
Acetate Rayon	3,800
Cotton	7,200
Silk	7,600
Wool	9,600
Viscose Rayon	9,800
Asbestos (Chrysotile)	130,000 to 220,000**

* Canadian Mining and Metallurgical Bulletin, April, 1951.
** Recent studies show that the maximum surface may run as high as 500,000 sq. cm./gram.

There is no quantitative data for a firm economic evaluation of the above improved properties. However, it can be reasoned that since the asbestos content does not add to the initial cost of the product as developed from conversations with suppliers, the increased life of the coating will not only give a direct economic benefit in the cost of the coating material, but also a saving in application costs which are in the same order as the cost of the material.

16.0 ASBESTOS-REINFORCED PLASTICS

> "Asbestos-reinforced plastics are polymeric materials to which asbestos fibers are added in order to modify the composite's physical and chemical characteristics. These composite materials are multi-component blends in which the asbestos fiber is the load-carrying member and the polymeric matrix fills the gaps between the fiber and distributes the applied stress to the fibers. The plastic material provides a shape and a smooth surface to protect the fibers and may also provide thermal or electrical resistance" (Daly *et al.*, 1976).

Asbestos fibers have been used in combinations with plastics for more than fifty years. The early applications in the 1920's were in asphalt floor tile, phenolic-molding compositions, and asphalt coatings. These were followed by vinyl-asbestos floor tile in the mid-1930's, and chemical-resistant equipment in 1933. Today, as in the past, the largest quantity of asbestos fiber used in plastics consists of the shorter grades, which function as fillers as well as reinforcing agents (Pundsack and Jackson, 1967).

The use of asbestos-reinforced plastics has expanded to products for the electrical and aerospace fields, chemical-resistant pipe and process equipment, friction materials, and thermoplastic molding and extrusion compounds. The larger uses of asbestos-reinforced plastics, such as floor-tile, friction materials, and gasketing, have already been discussed in earlier sections of this report. This section considers the other asbestos plastics uses, such as electrical and process equipment, and thermoplastic molding and extrusion compounds, as classified by the Bureau of Mines (Clifton, 1977). Additional data for all asbestos plastics is also presented.

Asbestos fibers are used to reinforce phenolic, urea, melamine, unsaturated polyesters, diallyl phthalate prepolymers, epoxies, silicones, polypropylene and nylon (Seymour, 1975). Their industrial, commercial, and residential uses are as ubiquitous as the term "plastic" implies (Daly et al., 1976). A small example of various asbestos-plastic products includes frying pan handles, nose cones for missiles and rockets, electrical motor components, distributor caps in automobiles, plastic molding components in automobiles, and corrosion-resistant pipe fittings, valves, tanks, fume hoods, fume stacks, and scrubbers.

16.1 Use Quantity and Economic Data

In 1976, 21,500 tons of asbestos fibers were consumed in the production of asbestos plastics as classified by the Bureau of Mines (Clifton, 1977). A breakdown of the various chrysotile grades and crocidolite and anthophyllite asbestoses used in 1976 is given below:

		Short Tons
Chrysotile	Grade 3	200
	4	2,800
	5	100
	6	1,200
	7	15,400
Crocidolite		700
Anthophyllite		1,100
	Total	21,500

The crocidolite and anthophyllite varieties of asbestos are utilized for specialty purposes where corrosion resistance is important, as their resistance to certain forms of chemical attack is superior to chrysotile.

Listed below is a breakdown of all the asbestos-reinforced plastics end-uses in 1976 (Clifton, 1977):

End-Use	Asbestos Consumption (short tons)
Floor Tile	113,500
Friction Materials	63,800
Gasketing	6,000 (SRC estimate)
All other	21,500
Total	204,800

Taken collectively, asbestos plastics are the second largest end-use of asbestos fibers; only the collective addition of all asbestos paper uses ranks higher. Reliable statistics on production of all types of reinforced plastics are difficult to obtain because a large percentage of producers are relatively small; however, in 1966, it was estimated that the U.S. consumed over 1.5 million tons of reinforcements and over 2 million tons of polymeric materials in producing over 3.5 million tons of laminated and reinforced plastics (Grove and Rosato, 1967). In 1966, approximately 0.3 million tons of asbestos fibers were consumed for plastic-type reinforcements (Clifton, 1975; SRC estimate); therefore, about 20% of all reinforced plastics in 1966 used asbestos fibers.

Statistics are not available for the current production of reinforced plastics; however, according to USITC (annual), production of plastics and resins had tripled from 1966 to 1976. Assuming a similar growth for reinforced plastics, over 4.5 million tons of reinforcements were used to produce over 10.5 million tons of reinforced plastics in 1976. From the above, about 0.2 million tons of asbestos fibers were used as plastics reinforcements in 1976; therefore, only 4.5% of all reinforced plastics in 1976 used asbestos fibers. Glass fibers are the most used reinforcing agents (Jenks, 1977). Asbestos plastics, as classified by the Bureau of Mines, would comprise less than 1% of the reinforced plastics market at present.

Consumption of asbestos for plastics reinforcement cannot be expected to increase significantly in the near future. Consumption for flooring and friction materials has fallen in recent years and a reversal of this trend is not expected. The 1972 OSHA ruling limiting airborne asbestos concentration triggered off a round of asbestos-free phenolic molding compounds by major producers

(MacBride, 1976). General Electric, at that time, for example, eliminated asbestos from their sizeable phenolic molding compounds production (Anon., 1972).

The number of manufacturers of asbestos plastics, as classified by the Bureau of Mines, is not readily available. A survey of the asbestos industry by Daly et al. (1976) estimated that the five asbestos-reinforced plastics plants surveyed used about 55% of the asbestos fiber in this classification. The Modern Plastics Encyclopedia (1977) lists two suppliers of asbestos-reinforced molding compounds: Rogers Corp. (Rogers, Conn.) and Plastics Engineering Co. (Sheboygan, Wisc.). The Rogers Corp. has a large plant which produces asbestos plastics in Manchester, Conn. (MacBride, 1976).

The cost of asbestos plastics can vary widely; for example, the cost of asbestos-phenolic resin products can range from $0.60/lb to $5.00/lb (Pundsack and Jackson, 1967). By current standards, the annual sales of asbestos plastics, as classified by the Bureau of Census, is probably on the order of $100 million (SRC estimate).

16.2 Manufacturing Process Technology

Figure 16.1 illustrates the general process flow for the manufacture of asbestos-reinforced plastics as classified by the Bureau of Mines. The asbestos fibers are introduced into a dry blending step which involves mixing the dry ingredients necessary to compound the material. Dry blending is needed to achieve a homogenous mixture of the ingredients which include asbestos fiber, catalysts, additives, resins, and polymers. A wide variety of equipment is used throughout the industry to insure a low-shear, well-mixed blend. The amount of asbestos present in the mix varies with the requirements of the final

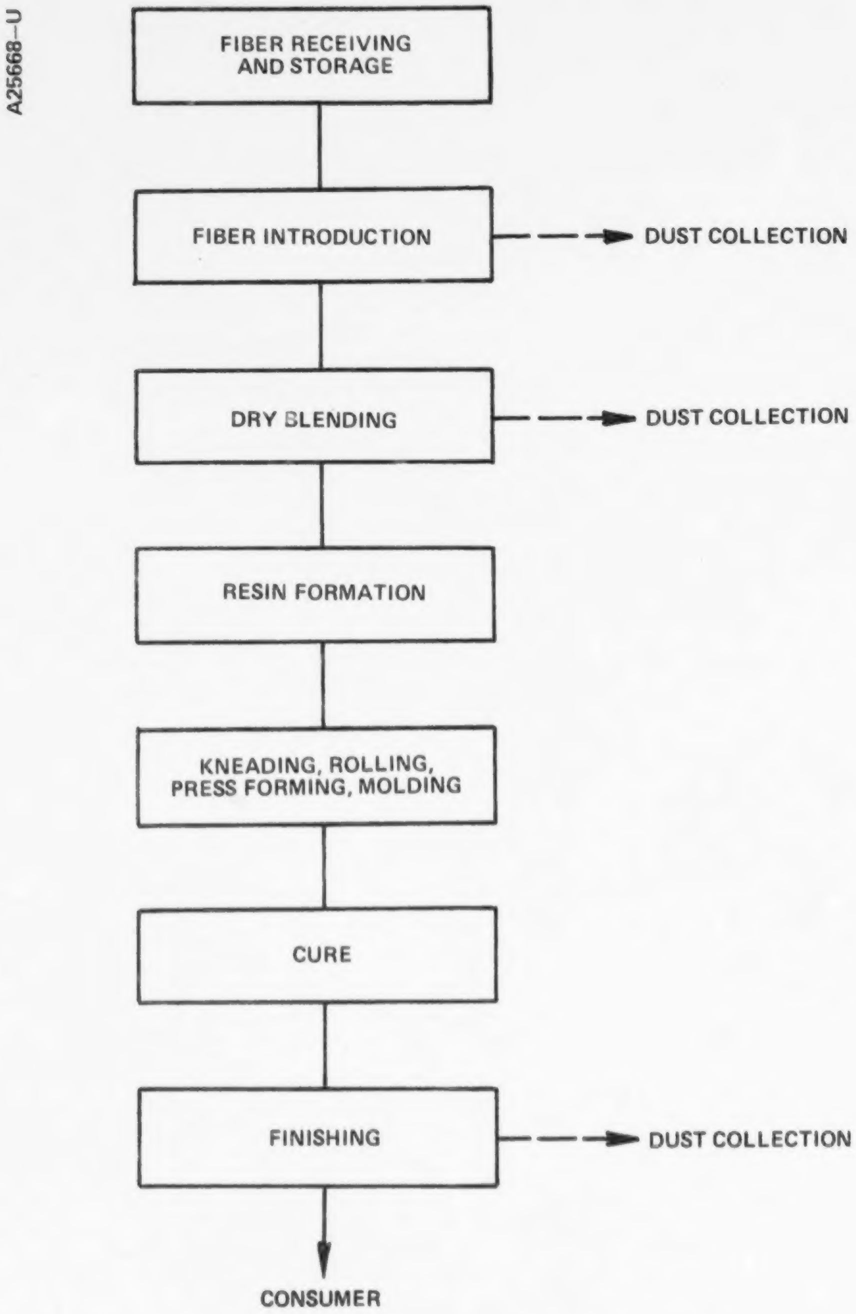
A25668–U
FIBER RECEIVING AND STORAGE
FIBER INTRODUCTION
DUST COLLECTION
DRY BLENDING
DUST COLLECTION
RESIN FORMATION
KNEADING, ROLLING, PRESS FORMING, MOLDING
CURE
FINISHING
DUST COLLECTION
CONSUMER

Figure 16.1. General Process Flow for Manufacture of Asbestos-Reinforced Plastics (adapted from Daly et al., 1976)

product. Some phenolic molding compounds contain 50-60% asbestos, while other resin products may contain as little as 5% asbestos; an average asbestos content of 20-30% appears to be most common.

From the blending step, the mixture is then formed into a resin. Some manufacturers refer to this step as a "preforming" operation in which the mixture is heated by steam or electricity as in extrusion, or by internal shearing friction as in a Banbury mixer. The product from these operations is a pellet, powder, or some similar "preform" which is either packaged and sold as an intermediate product or conveyed directly to a type of forming process.

> "The forming step involves actual formation of an end product from the preformed resin. The polymer portion of the resin is the shape-forming ingredient of the preform. The final product is shaped by remelting the preform and submitting it to rolling, stamping, pressing, or molding. Remelting serves to start the polymerization, cross-linking, and thermosetting reactions; forming gives the desired shape of the end product" (Daly _et_ _al_., 1976).

> "Following the molding process, the formed product is cured. This step involves control of cross-linking and thermosetting reactions to achieve specified strength and stiffness characteristics. When the reactions are carried to their desired ends, the rough product is then sent to a finishing step. Finishing operations are similar to other asbestos industry segments in that they involve sanding, grinding, polishing, drilling, sawing, etc. The degree of finishing (e.g., rough sanding vs. polishing) is dictated by product uses and the variety of applications of these plastic materials" (Daly _et_ _al_., 1976).

Although there are considerable variations to the asbestos-reinforced plastics manufacturing steps, the above description is common to nearly all products (Daly _et_ _al_., 1976).

16.3 Release of Asbestos to the Environment from Manufacture

Water is not used in the manufacture of asbestos-reinforced plastics, except in the capacity of heat exchange fluid. As was the case for asbestos floor tile, water does not come into contact with the asbestos-resin until the product is inert, that is, the polymer matrix has been formed and the fibers are tightly bound by the matrix. Therefore, there is virtually no release of asbestos to the environment from process wastewaters. Asbestos would be released in wastewaters from water-type air scrubbers which could be used to clean factory air; however, baghouse collectors are normally used for this function. For example, the Rogers Corp. plant in Manchester, Conn. is equipped with 10 baghouse collectors handling air emissions containing asbestos fibers (MacBride, 1976).

The primary loss of asbestos from manufacture results from product scraps, damaged products, and air and vacuum cleaning collections. Unfortunately, there is no direct available monitoring data by which to quantify these losses. However, it may be possible to quantify these losses by an indirect method. In Section 6.6.1, it was estimated that approximately 12.7% of the asbestos in friction materials manufacture was lost to all types of scraps. The large bulk of this 12.7% loss resulted from grinding, trimming, and finishing of the friction product. This kind of finishing is also done to the asbestos plastics, as classified by the Bureau of Mines. Asbestos dust is released when these plastic products are finished (Daly et al., 1976). Hand and portable tools are normally supplied with local exhaust systems connected to the central ventilation/collection system; in addition, work areas are connected to the ventilation/collection system (Daly et al., 1976). The severity of dust release from grinding, trimming, and finishing for asbestos plastics is not judged to be as great as for friction materials. Therefore, it is estimated that perhaps 6% of production is lost to product scraps and baghouse collections, with baghouses collecting perhaps two-thirds of this total. On a basis of an annual asbestos usage of 21,500 tons, about 860 tons of asbestos would be collected by baghouses and about 430 tons of asbestos would be contained in coarser product scraps.

The asbestos in the coarser product scraps is not recovered for reuse because once the resin has set up, it is not regarded as economical to break it down to salvage the fiber. Therefore, these scraps are removed to landfills and waste dumps. Because the fibers are coated with polymeric materials, the release of free-fibers to the environment is not likely.

The asbestos fines collected by baghouses are recyclable as a filler material. At the Rogers Corp. Manchester plant, the accumulated fines are wetted for reuse in beater operations (MacBride, 1976). Assuming the baghouses are 99.99% efficient, as described by Siebert et al. (1976), then about 0.086 tons of free-fibers would be annually emitted to the atmosphere by baghouses. The alternative conversion factor developed in Section 7.3.1 would estimate this release to be significantly higher.

According to the Rogers Corp., the only free-fibers of asbestos sent to waste are contained in emptied bags, in which the fibers were shipped to the factory (MacBride, 1976). Special precautions are taken to dispose of these bags in landfills.

A summary of asbestos releases from plastics manufacture is given below:

	Quantity (short tons)	Comment
To water:	none	
To waste dump or landfill:		
products scraps	430	Fibers coated with polymer matrix
To air:		
baghouse emissions	<0.1 to ∿ 1	Free-fibers

16.4 Fiber Release from Product Use

The diversified uses of asbestos-reinforced plastics complicate this particular discussion. In general, most of these plastic products are not designed to have a service life greatly in excess of ten years or so. Therefore, a sizeable percentage of production is intended for replacement-type purposes. It may be estimated that perhaps 80-90% of production goes for replacement purposes (SRC estimate). The annual wasting of asbestos plastics may therefore be in the range of 18,000 tons. These wastes will be disposed primarily to commerical landfills and auto junkyards (asbestos plastics have significant usage in automobiles). Because the asbestos fibers are tightly bound in the plastic matrix, the replacement wasting of asbestos plastics is not judged to cause any significant free-fiber releases to the atmosphere.

During the service life of an asbestos plastic product, it is difficult to envision any fiber release, due to the matrix bonding, unless the product is subjected to friction, scraping, sanding, rubbing, or some other physical force which could break down the plastic matrix. With the exception of friction materials, as discussed in Section 6.0, these forces are apparently not common to asbestos plastics. Therefore, the actual use of most asbestos plastic products would not seem to constitute any threat for free-fiber releases.

It should be noted that monitoring data is not available for determining potential free-fiber releases from asbestos plastics usage as classified by the Bureau of Mines. Unless the particular product is commonly subject to some physical force, such monitoring is probably not worthwhile.

16.5 Alternatives

A wide variety of alternative fibers to asbestos are available as reinforcements and fillers in plastics. Such alternatives include carbon, aranid, glass, fiberglas, hybrids, cellulose, ceramic, metallic, chemical, and various mineral and synthetic fibers (Seymour, 1975). As discussed in Section 16.1, the use of asbestos fibers for all types of plastics reinforcement has fallen in recent years and is not likely to rebound. However, the reasons for this decline can be attributed to use of alternative products and OSHA regulations causing some manufacturers to stop using asbestos, but cannot be attributed to replacement of the asbestos by a different fiber in most cases.

In earlier sections of this report, it has been stated that asbestos is endowed with the useful characteristics of high strength, corrosion resistance, high heat performance, and a comparatively low price. This cannot be said for any available alternative fiber. However, if the intention of fiber reinforcement is only for strength or only for corrosion (as examples), then asbestos is not necessarily needed and is not, probably, commercially used at present. However, there are applications which require all of asbestos's characteristics. According to the Rogers Corp., which decided to stick with asbestos reinforcements despite OSHA regulations, high-heat performance and economic requirements preclude the use of anything but asbestos as a filler system for phenolics, particularly in the growth-potential automotive and appliance industries (MacBride, 1976).

17.0 MISCELLANEOUS ASBESTOS USES

This section discusses the various miscellaneous end-uses of asbestos fibers in their particular applications and attempts to quantify use volumes and environmental releases where possible. The Bureau of Mines' end-use quantity statistics for asbestos used throughout this report (Clifton, 1975, 1977) were obtained by mail surveys of the major asbestos users, producers, and importers (Clifton, 1978). The survey questionnaire contained answer spaces for consumption of the major end-uses as listed in Table 4.10. All other use consumptions not specifically stated on the questionnaire were listed under a miscellaneous classification. Therefore, the Bureau of Mines has absolutely no breakdown of the uses listed under miscellaneous; the total asbestos fiber consumption of this miscellaneous class in 1976 was 23,900 short tons (Clifton, 1977). A breakdown of the various types and grades of asbestos used is the following (Clifton, 1977):

Chrysotile -	Grade 3	300 short tons
	Grade 4	800 short tons
	Grade 5	2,500 short tons
	Grade 6	4,400 short tons
	Grade 7	14,700 short tons
Amosite		1,200 short tons

Table 17.1 lists the approximate quantities of asbestos fibers consumed in specific miscellaneous end-uses as were available from literature and various personal contacts.

It should be noted that the Bureau of Mines does not survey all users and sellers of asbestos fiber, especially the small volume users or small volume retailers. In this regard, the total consumption figures listed by the Bureau of Mines are slightly less than might actually be the case. For example, "raw

Table 17.1. Asbestos Consumption of Specific Miscellaneous End-Uses

End-Use	Consumption (short tons)	Year
Patching Compounds	10,000	1976 (Kearney, 1977)
Drilling Muds	10,000	1977 (Asbestos Information Assoc., 1978)
Asphalt-Asbestos Cement	< 100	1977 (Koliber, 1978)
Shotgum Shell Base Wads	500	1974 (EPA, 1974)
Fake Fireplace Ashes	5	1976 (SRC Estimate)

asbestos is purchased by wholesalers and warehousers in 100-pound bags, repacked in small quantities, and sold to retailers. These wholesalers repackage the asbestos in 5- to 25-pound bags for resale. The ultimate customer may be a plumber who uses the asbestos in a cement compound for repair of boiler or pipe insulation" (Daly et al., 1976). The volume of asbestos used for these various applications is virtually impossible to quantify. Also, what percentage of these uses is included in the Bureau of Mines' figures is difficult to predict.

The following subsections discuss the various end-uses in the miscellaneous category in terms of production, application, and environmental release.

17.1 Patching Compounds

An economic assessment of the patching compound market has been produced by Kearney (1977) which gives an overview of the entire patching compound industry. As a result of this study and other studies which concluded that patching compounds containing asbestos pose health risks to consumers, the Consumer Product Safety Commission has banned the consumer sales of patching compounds containing asbestos (Anon., 1977c). However, the Consumer Products Safety Commission apparently does not have jurisdiction over industrial applications of patching compounds; for this reason, the production of asbestos patching compounds is continuing and will continue, according to various industrial spokesmen.

According to the Asbestos Information Association, about 10,000 tons of asbestos were annually consumed in patching compounds (Kearney, 1977). The ban imposed by the Consumer Product Safety Commission will effectively reduce this consumption, but the degree of reduction is not certain at this time. In 1976, Kearney (1977) estimated that 5-10% of annual sales were for purely industrial applications; this would indicate that at least 500 to 1,000 tons of asbestos will continue to be consumed in patching compounds.

Approximately 50 firms have been identified as manufacturers of patching compounds. Three major firms (Georgia Pacific, National Gypsum, and U.S. Gypsum) produce nearly one-half of all patching compounds; however, none of them claim to be using asbestos (Kearney, 1977). The annual value of all patching compound shipments in 1976 was estimated to be roughly $120 million (Kearney, 1977). Since about one-half of all patching compounds sold contain asbestos (Anon., 1977c), or did contain asbestos, then perhaps sales of asbestos patching compounds were roughly $60 million in 1976.

17.1.1 Application and Manufacture of Patching Compounds

Joint cements, or patching compounds, are used to finish the installation of wall board for industry and home applications. The construction industry and the do-it-yourself home installations use this material. Types of patching compounds, by application, are listed in Table 17.2.

> "There are two principal types of joint compounds. One uses a latex or water-soluble glue as a binder and "sets" by evaporation of the water. The other uses dehydrated gypsum as the binder (and principal dry ingredient) and sets by chemical reaction as the gypsum takes up water of hydration. The first type is mainly limestone with lesser amounts of mica and 3-5 percent asbestos. This type is used in about 80 percent of the market, and is mostly sold in the ready-mixed, wet form. The gypsum-based material, with roughly 20 percent of the market, also usually contains asbestos and must naturally be sold dry and mixed just before use. The applicator mixes the compound with water in the field. Wet-mix products are manufactured and packaged in a can for ready use" (Daly *et al*., 1976).

"The manufacturing of joint cements incurs the common exposure potentials for handling raw asbestos fibers when bags are stored, moved, slit, dumped, and disposed of. The raw asbestos fiber is dry-blended or alternatively

Table 17.2. Types of "Patching Compound" by Application (Kearney, 1977)

Types of "Patching Compound"	Application
1. Patching plaster or spackle (a generically used trade name.)	1. Repair of small cracks and imperfections in plaster or gypsum wallboard interior walls
2. Tape joint cement or compounds used with a tape This product includes specialized drywall formulations:	2. Major repairing or finishing of large interior wall cracks. The most common application is for covering the cracks between newly erected drywall panels
a. Taping formulation	a. Applied in the first one or two coats; designed for strength
b. Finishing	b. Applied in the final coats; designed for a quality finish with minimal sanding
c. General purpose	c. A compromise formulation designed for both taping and finishing; also often used for small repair applications (1 above)
b. and c. (Note: Currently, texturing compounds labelled as such, are not typically used as "patching compounds")	Both b. and c. are also often used as texturing compounds to achieve decorative wall and ceiling finishes

transferred to wet mixing before packaging" (Daly et al., 1976). The wet-mix patching compounds are manufactured in a similar fashion as previously described in other sections (9 and 15) of this report for mastic and bitumastic mixtures; therefore, details are not included here.

"The product flows from the manufacturer, to wholesalers, to retailers, to small contractors, and finally to appliers. The wet-mix product has little potential for asbestos fiber exposure until it is finally applied and allowed to dry. Sanding the product after it has dried can generate dust" (Daly et al., 1976).

17.1.2 Environmental Asbestos Release from Manufacture

Patching compounds, or joint cements, are manufactured similarly to asbestos-mastic or bitumastic mixtures. In this regard, the only environmental release of free fibers will occur from baghouse emissions to the atmosphere and from wasted empty asbestos shipment bags. The Siebert et al. (1976) baghouse efficiency of 99.99% would estimate baghouse releases to the atmosphere to be less than 0.1 ton of fibers per year for the entire industry. Baghouse collections of fibers can be recycled rather than wasted. Additionally, product scraps are minor; cleaning and washing of equipment create only minor releases, but in these releases, the fibers are encapsulated by the binder. There are no wastewater releases of asbestos except, perhaps, in cleaning wastes.

17.1.3 Environmental Asbestos Release from Use

The Consumer Products Safety Commission has concluded that use of patching compounds by consumers may constitute a health risk to the users (appliers) and has, therefore, banned consumer sales of these compounds. According to the CPSC, "asbestos fibers are released into the air after application, when the patching compound is sanded or scraped in the process of finishing or smoothing the surface. Asbestos may also be released into the air when the dry form of patching compound is mixed with water prior to use" (Anon., 1977c).

The fiber concentrations in air during use of patching compounds are given in Table 17.3 from available monitoring data. Unfortunately, there is not enough information available to precisely quantify these releases of free fibers.

Product scraps left in supply containers may comprise roughly 1% of production; these scraps, in which the asbestos fibers are encapsulated by binders, are typically disposed to local landfills and garbage dumps.

The amount of patching material which requires sanding or scraping depends upon the nature of the job and the proficiency of the applier. Assuming that roughly 1% of production undergoes sanding or scraping, then about 100 tons of scrap material (asbestos) are produced annually on a production basis of 10,000 tons. This scrap material, which does contain free-fiber asbestos, may be disposed to garbage dumps from floor sweepings or washed down drains to sewers or rivers. The CPSC product ban will lower the above estimate because production will be reduced; also, in the industrial areas of continued use, installations should primarily be done by professional workers, which should cut down on waste. Professional workers are also more likely to be equipped with tools which are capable of collecting dusts generated by sanding, etc. via vacuum devices. Asbestos dust and particles which may be collected (which could total in the neighborhood of 10 tons annually on a 1,000 ton production basis) may require special precautions for disposal, as the fiber could become airborne.

Table 17.3. Asbestos Fiber Concentrations During Use of Patching, Joint, and Tape Compounds (Rohl *et al.*, 1975)

Operations	Number of samples	Peak fiber concentration (fibers per milliliter) Mean	Range
Pole-sanding (1 to 1.5 m)	10	10.0	1.2 to 19.3
Background (2.5 m), same room	3	8.6	3.5 to 19.8
Background (7.5 m), adjacent room	2	4.8	0.7 to 8.8
Hand-sanding (1 to 1.5 m)	11	5.3	1.3 to 16.9
Background (2.5 m), same room	2	2.3	2.1 to 2.5
Background (4.5 m), adjacent room	2	4.3	1.5 to 7.1
Dry mixing (1 to 1.5 m)	2	47.2	35.4 to 59.0
Background (3 to 6 m), same room	3	5.8	0.5 to 13.1
Background (5 to 10 m), adjacent room	2	2.6	2.1 to 3.1
Sweeping floor (3 to 15 m)			
15 Minutes after sweeping	1	41.4	
35 Minutes after sweeping	1	26.4	

As is the case for most asbestos end-uses, the largest environmental disposal of patching compounds occurs when products are replaced or demolished. Service life-time may be for many years. In most of these replacement scraps, the fibers should be bound in the binder; however, removal may cause an undetermined percentage of the fibers to become airborne. Wetting according to EPA demolition procedures should reduce airborne dust concentration. Replacement scraps are normally hauled to landfill sites for disposal.

17.1.4 Alternatives

Approximately one-half of all patching compound produced in 1976 did not contain asbestos. The percentage of non-asbestos patching compounds will grow due to the CPSC ban. Therefore, asbestos replacement in these particular compounds is not only theoretically possible, but is indeed a commercial reality.

However, many commercial users of non-asbestos patching compounds believe them to be inferior to asbestos patching compounds.

"For commercial application, manufacturers consider asbestos to be a critical constitutent which contributes to the workability and ease of application of the compound and contributes to the appearance of the finished wall joint. Efforts to substitute other materials for asbestos have generally resulted in products considered by professional drywall finishers to be inferior in performance and require more labor to use" (Kearney, 1977).

> "Formulations are closely-held secrets and have been developed after years of trial and error research and experimentation. The few formulators who were willing to discuss their work admitted a certain lack of understanding as to why asbestos uniquely seemed to impart the qualities required for an efficient and durable product" (Kearney, 1977).

> "Formulators who claimed to have identified satisfactory substitutes for asbestos note that asbestos could not be replaced with one ingredient. Rather, a complex of several compounds was required to optimize the 10 to 15 desirable characteristics of a tape joint compound. Workability (thixotropicity), water retention, decreased need for sanding, and crack-free drying properties were reported as extremely important. Further, these formulators reported their asbestos-free products were frequently more sensitive to variations of job-site temperature and humidity than their asbestos containing formulations" (Kearney, 1977).

17.2 Drilling Muds

"Drilling fluids (muds) are essential for drilling oil and gas wells. The use of asbestos in drilling muds is well-established and can have a significant effect on lowering the cost of drilling and completing wells. Drilling muds are pumped down through the drill pipe and back up the annulus between the drill pipe and the well bore wall. When they arrive back on the surface, they flow over a shaker screen to remove the drill bit cuttings, and into a mud pit. The fluid is then recirculated through the hole. Materials needed to maintain the properties of the drilling fluid are added in the surface pit" (Daly *et al.*, 1976)

"The main function of the drilling mud is to remove drill cuttings from the hole and to contain formation pressures in the hole. The mud also removes heat from the drilling action, acts as a lubricant, and prevents excessive hole erosion. The drilling mud must be such that it remains fluid enough to be pumped with minimum pump pressures. It must not be lost to the formation, yet it must overcome formation pressures to prevent ingress of oil, gas, or water" (Daly *et al.*, 1976).

"Asbestos is added to the drilling mud to improve its carrying capacity without appreciably increasing the viscosity. Other methods of improving the carrying capacity markedly increase viscosity, which increases pump pressures, thus reducing the power available at the bit and slowing down drilling. Slow drilling rates increase drilling costs. Asbestos is used in concentrations of from 2-5 pounds per barrel (1 barrel = 42 gallons) of mud" (Daly _et al._, 1976).

"Asbestos is added to the drilling fluid through a mud hopper or large funnel. Initially, a volume of mud of from 150 to 200 barrels is prepared. As drilling progresses, additions are made to the system for maintenance and to accomodate the volume of the hole being drilled. Typically, these conditions occur only once during an 8-hour shift. The amounts of asbestos added are small -- rarely exceeding 500 pounds at a time" (Daly _et al._, 1976).

"Over 30,000 wells are drilled per year in the U.S., using around 1,500 drilling rigs. The frequent moving from site to site makes fixed control equipment for asbestos fiber exposure infeasible. A normal drilling crew consists of four men working an 8-hour shift; that is, three 8-hour crews per day. Drilling sites may be miles from any population center and are subject to extremes of climatic conditions (for example, the north coast of Alaska to the Gulf of Mexico)" (Daly _et al._, 1976).

According to the Asbestos Information Association (AIA), the quantity of asbestos fiber annually consumed for drilling fluids is approximately 10,000 tons. The shorter grades of chrysotile fibers are normally used; pelletized fiber as well as loose fiber can be utilized.

17.2.1 Environmental Emissions

Asbestos is added to the drilling fluid at the job site; therefore, manufacturing emissions, in the conventional meaning, are non-existent. During the addition of asbestos to the drilling fluid, an undetermined quantity of fibers becomes airborne. Release may be partially dependent upon weather conditions; for example, a greater number of fibers may be released during windy weather. Once the fibers are encapsulated by the mud, however, airborne releases are unlikely to occur. Also, use of pelletized asbestos should significantly reduce airborne emissions. Lacking monitoring data, it is judged that perhaps 0.5% of the asbestos consumption for drilling fluids is lost during on-site mixing, or roughly 50 tons per year. These releases will probably settle on the ground or be washed by rain, etc. from the air and eventually become stabilized in ground or river sediments.

When drilling fluid is used, mud pits are usually dug or set up next to the drilling rig (see Figure 17.1). Discussions with drilling contractors indicate that when drilling operations have been completed, the mud is usually dumped or left in the mud pit and covered over with dirt; a sort of on-site landfill. Occasionally, the mud may be transported to a new drilling site when the new site is nearby. Airborne release of asbestos fibers from drilling muds would appear to be unlikely because the fibers are encapsulated.

17.2.2 Alternatives

Asbestos is added to drilling fluids to increase the density, to improve viscosity, and to reduce whole fluid loss. Asbestos is apparently unique in being able to add to all three of these characteristics of drilling fluids. However, many other materials are commercially used to give these properties to drilling fluids. Choice of drilling fluids is apparently determined by application of the individual job, soil characteristics, materials being drilled for, and cost-effectiveness. Asbestos apparently comprises less than 2% of all drilling fluid materials (SRC estimate).

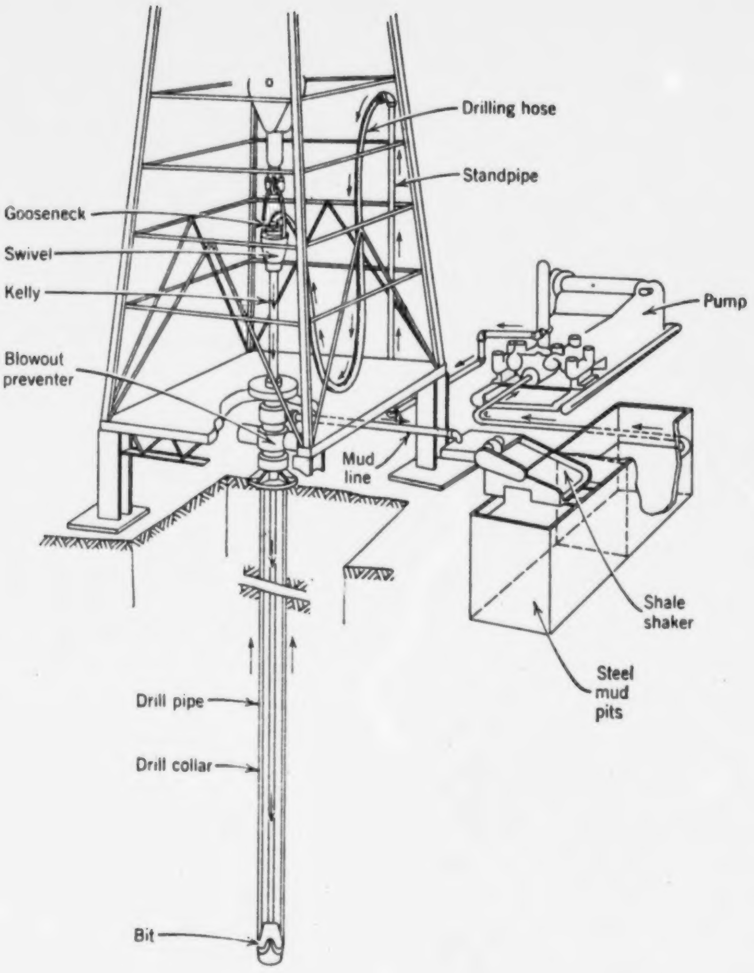
Drilling hose
Standpipe
Gooseneck
Swivel
Kelly
Pump
Blowout preventer
Mud line
Shale shaker
Steel mud pits
Drill pipe
Drill collar
Bit

Figure 17.1. A Circulatory System for a Rotary Drilling Rig (Huebotter and Gray, 1965)

Barite (natural barium sulfate) is the most extensively used material for increasing the density of drilling fluids (Huebotter and Gray, 1965). Materials used to control viscosities include bentonite, attapulgite, organophilic clays, various polyelectrolytes and coagulants, and ferrochrome lignosulfonate among others. Materials used to prevent whole fluid loss (that is, to bridge and plug holes and cracks and to seal highly permeable soils and rocks) include many substances, such as cottonseed hulls, mica, and various granular, fibrous, and flaky type materials (Huebotter and Gray, 1975).

17.3 Asphalt-Asbestos Concrete

Asbestos is added to asphalt to give it greater strength and longer wear life. An asbestos-asphalt aggregate mixture has occassionally been applied as a thin topping layer to airport roadways, bridge decks, and street curbings. In 1974, about 50 of the estimated 5,000 asphalt concrete plants in the United States used asbestos in aggregate mixtures each year, and the total amount of asbestos consumed by individual plants varied greatly from year to year (EPA, 1974). Approximately 4,500 short tons of asbestos fibers were consumed in 1974 for the production of asphalt concrete (EPA, 1974). However, various environmental restrictions applied to manufacturing plants and concerns about adverse health effects of asbestos fibers have caused consumption of asbestos in asphalt concrete to fall markedly since 1974. According to a spokesman for the National Asphalt Paving Association (Koliber, 1978), current use of asbestos in asphalt concretes is less than 100 tons per year. In the near future, it is likely that this particular application of asbestos will no longer be used. It is the policy of the National Asphalt Paving Assoication (NAPA) to discourage the use of asbestos in asphalt mixtures because asbestos does not improve the properties of the mixture enough to offset environmental considerations (Koliber, 1978). Also, certain polyester fibers produced by DuPont can be substituted for asbestos in this use and still make a useable and economically viable product (Koliber, 1978).

17.3.1 Manufacturing and Emissions

In the manufacturing process, asbestos is mixed with dried aggregate. After a short dry mixing time, hot liquid asphalt is added to the asbestos-containing aggregate and thoroughly mixed (EPA, 1974). As is the case for other asphalt, mastic, and bitumastic processes using asbestos, the only source of environmental release of free-fibers from manufacturing occurs from bag openings and disposals and dry mixing. Considering the current asbestos consumption is less than 100 tons per year, emissions from baghouses or other collection devices are probably very small. In any product scraps which may be disposed, fibers are encapsulated by the asphalt mixture and cannot become airborne.

17.3.2 Emissions from Product Use

Asbestos-asphalt concrete toppings have been applied to bridge decks, airport roadways, and street curbings. It is possible that normal automobile or airplane traffic using these surfaces may enable asbestos fibers to become airborne from surface wear. An exact estimate of the quantity or mileage of asbestos-asphalt concrete surfaces in current use is not available.

17.4 Shotgun Shell Base Wads

Only one shotgun shell manufacturing plant in the United States is known to use commercial asbestos; that plant is located in Bridgeport, Conn., and is operated by Remington Arms Company (EPA, 1974). Personal contacts with

Remington Arms' representatives indicate that asbestos is currently being used; however, the exact annual use quantity was not available. In 1974, approximately 500 tons of asbestos were consumed for shotgun shell production (EPA, 1974). Current use is judged to be approximately the same.

"Asbestos is used to manufacture base wads for shotgun shells. The asbestos is mixed with wood flour and wax, and then pressed into base wads. The weight composition of the final mixture is about 54 percent wood flour, 36 percent asbestos, and 10 percent wax. Asbestos emissions can occur during asbestos addition to the mixture, during mixing operations, and at the wad presses. The emission points are vented to the outside air through particulate collection devices" (EPA, 1974).

17.4.1 Manufacturing Emissions

Process water is not used during manufacturing; therefore, the only asbestos which could be released in waste waters would result from cleaning operations. Such releases are judged to be minor. Product scrap wastes are also judged to be minor.

The major source of emissions occurs from baghouse operations and exhausts. During the course of a year using 500 tons of asbestos in production, roughly one ton of asbestos fibers will be collected in the baghouses by assuming 0.2% of production in air vented to the collectors as was assumed in Section 9.3.4 for a similar manufacturing operation. Baghouse collections are recyclable. Emission quantities to the atmosphere from baghouse exhausts are very small when the Siebert et al. (1976) baghouse efficiency of 99.99% is applied.

17.4.2 Use Emissions

When a shot gun shell is fired from a gun, the base wad is normally expelled from the cartridge and is commonly fragmented into many separate pieces. Monitoring data for asbestos fiber release is not available; however, it may be possible that free fibers are released when a shotgun is discharged with an asbestos-containing base wad.

17.4.3 Alternatives

Other shotgun shell manufacturers apparently do not use asbestos in making base wads, so alternatives to asbestos for this application are commercially available. The exact need for asbestos in some base wads is not clear.

17.5 Artificial Fireplace Ashes

In addition to asbestos joint cements, the Consumer Products Safety Commission has banned the consumer sales of artificial fireplace ashes containing asbestos (Anon., 1977c). In mid-1977, manufacturers stopped producing asbestos fireplace ash in anticipation of a consumer ban (Ray, 1977). This should effectively eliminate this application of asbestos in the future.

Artificial fireplace ashes or emberizing materials are decorative, simulated ashes and embers which are used in some gas-burning fireplace systems to give the appearance of burning embers. They serve strictly a decorative purpose. Artificial emberizing material is sprinkled on or glued to gas logs, or sprinkled on fireplace floors (Ray, 1977).

Between 1971 and 1976, over 100,000 gas logs were reported sold which were frosted or treated by consumers with asbestos-containing materials (Ray, 1977). During 1976, this would indicate that roughly 20,000 gas logs were asbestos-treated. Asbestos quantity per log would normally be less than half a pound; therefore, in 1976, only about 5 tons of asbestos (chrysotile) were used for artificial embers.

Substitute materials for asbestos in artificial embers have been commercially developed and distributed. These substitutes include Cerafiber, which is a synthetic fiber developed by Johns-Manville, as well as rock wool, vermiculite, and mica (Ray, 1977).

17.6 Other Uses

Other notable uses of asbestos, which have not been classified in any of the Bureau of Mines' major end-use categories, include formed or spray-on insulations, artificial snows, and foundry sands.

Formed or spray-on type insulations containing asbestos have been nearly phased out of current commercial productions (Section 12.1). However, retail sales of asbestos fiber, in small quantity lots, are probably being used for these purposes.

Artificial snows, for decorative purposes, are apparently no longer being made with asbestos fibers. It can be assumed that health considerations caused production to stop. Annual use quantities were probably quite small, anyway.

Asbestos has been mixed into foundry sands for special mold applications. Discussions with local foundries have indicated that OSHA regulations have virtually put an end to the use of asbestos in foundry sands. A very good alternative to asbestos for its special applications, wollastonite, is now being used. Wollastonite is a naturally occurring calcium silicate found in metamorphic rocks.

18.0 SUMMARY OF ASBESTOS END-USES AND EMISSIONS FROM MANUFACTURE AND PRODUCT USE

The quantity of asbestos used for various end-uses is presented in Tables 4.9 and 4.10 and is also presented in the individual sections throughout this report. For the most part, these quantitative figures have been determined by the Bureau of Mines (Clifton, 1977). As has been explained in individual sections, some of the end-use categories, as presented by the Bureau of Mines, are considered to overlap. For example, the roofing end-use contains quantities of asbestos fibers used to make paper, asphalt coatings, A-C sheet, and A-C shingles; asbestos textiles are grouped into the insulation, friction materials, and gaskets and packing classes as well as its own class. Other overlaps also occur.

Table 18.1 gives a breakdown of the quantities of raw asbestos fiber consumed in the primary manufacturing operations; overlaps have been eliminated to the best possible degree from available data. Table 18.1 is intended to list the asbestos fiber usage by each segment of the asbestos industry. Daly *et al*. (1976), in cooperation with the Asbestos Information Association, surveyed the entire asbestos industry to determine the asbestos fiber usage of each industry segment, among other data. Comparison of Table 18.1 and the data tabulated by Daly *et al*. (1976) reveals good agreement; the percentage of usage does not vary more than several percent for any classification. As can be seen from Table 18.1, more than one-third of all raw asbestos fiber is used to make paper.

18.1 Asbestos Emissions from Manufacturing

The estimated environmental disposals and releases of asbestos from manufacturing are listed in Table 18.2. The estimates in Table 18.2 consider

Table 18.1. Asbestos Fiber Usage for Each Industry Segment in 1976 (SRC estimates; Clifton, 1977; various personal contacts)

Industry Segment	Tons Consumed	Percent of U.S. Asbestos Usage
Paper	260,600	35.5
A-C Pipe	140,000	19.1
Flooring	113,500	15.4
A-C Sheet	55,000	7.5
Friction Materials	54,200	7.4
Coatings and Paints	38,000	5.2
Textiles	26,200	3.6
Plastics	21,500	2.9
Drilling Fluids	10,000	1.4
Joint Cements	10,000	1.4
Gaskets and Packing	5,200	0.7
Other	**	
Total	733,200	

** Undetermined, but probably less than five thousand tons.

Table 18.2. Environmental Disposals and Releases of Asbestos from Manufacturing (quantities in short tons)

	Amount Collected in Baghouses***	Total Amount to Landfills or Waste Piles	Amount in Free-Fiber Form to Landfills or Waste Piles	Amount in Wastewaters to Surface Waters
Paper	1,173	2,380	**	46-98
A-C Pipe	737	11,897	737	11-12.5
Flooring	227	**	**	**
A-C Sheet	210	3,408	210	3.8
Friction Materials*	6,100	8,137	6,100	0.3
Coatings and Paints	75	**	**	**
Textiles*	150	<350	150	**
Plastics	860	230	**	**
Drilling Fluids	0	10,000	**	**
Joint Cements	20	**	**	**
Gaskets and Packing	10	40	**	**
Totals	9,562	36,442	7,197	61.1-114.6

[*] Textiles used in making friction materials are listed in friction material collections and releases; no other overlapping data is included.

[**] Relatively very small quantities.

[***] See text for amount of free-fibers released from baghouses.

the primary manufacturers and most of the secondary manufacturers. The estimates were extracted from Sections 6.0 through 17.0 of this report; the methods describing how the estimates were made are given in those sections. As was the case for Table 18.1, Table 18.2 consolidates estimates for the various industry segments; for example, the release and disposal estimates for paper can be obtained by adding the individual estimates for paper in the roofing, paper, gaskets and packing, and insulation sections. It should be noted that most of the estimates were derived from engineering assumptions and not from direct monitoring data. Direct monitoring data were available for A-C pipe (Harwood and Ase, 1977). Indirect monitoring data was available for friction materials (Jacko and DuCharme, 1973; EPA, 1974) and for wastewater effluents from various industry segments (Carton, 1974; Stewart et al., 1976).

Although the estimates in Table 18.2 appear to be rather exact quantities, they should definitely not be considered as such. At best, these estimates should be considered as "ballpark" figures. The generation of precise release estimates would require a vigorous and extensive monitoring program which has not been conducted to date.

Manufacturing emissions can, of course, be released to land, water, or air. Table 18.2 estimates that in the neighborhood of 5% of the total amount of asbestos consumed by manufacturing in 1976 was disposed to landfills or waste piles, and of this amount, perhaps one-fifth was in free-fiber or potentially respirable fiber form. Most of this free-fiber asbestos disposed to landfills was generated by baghouse collection and then disposal; also included in this quantity is free-fiber asbestos collected and disposed from vacuum cleaning type devices. Disposal methods of these baghouse collections vary from plant to plant; in some plants, the collections are apparently dumped on a waste pile with no further treatment while other plants may bag and bury these wastes. The method of disposal will obviously affect the potential for the free-fibers to become airborne. However, in perhaps four-fifths of the amount of asbestos wasted to landfills and waste piles, the asbestos fibers are tightly bound in some sort of matrix binder such as cement, asphalt, plastic, or resins. It is unlikely that free-fiber asbestos is released to become airborne from this matrix unless the scraps are crushed or incinerated or acted upon by some similar physical force. This is apparently not the case, when considering manufacturing wastes, with the exception of A-C pipe as detailed in Section 7.0. It is visualized, for the most part, that the matrix bound asbestos wastes will eventually become stabilized in the ground sediment of the landfills or waste piles and be virtually unable to contaminate the air with free-fiber asbestos. Ground waters may be able to leach fibers from some products which are matrix bound; however, there is no monitoring data which would suggest this action. Ground waters may be able to leach free-fiber asbestos from waste piles or landfills if they are not contained in some precautionary manner.

The amount of asbestos released to surface waters from manufacturing wastewaters is estimated in Table 18.2 to be roughly 100 tons annually. This estimate is, of course, dependent upon the efficiency of clarifying equipment at each individual manufacturing location. The results in Table 18.2 tend to agree with Stewart's et al. (1976) finding that "plants manufacturing asbestos paper present the greatest potential for contamination of surface waters by asbestos." It should be pointed out, however, that Stewart et al. (1976)

monitored relatively high asbestos concentrations upstream as well as downstream from plant discharge points. At times the water entering the paper plant was as contaminated with asbestos as when it left. It has been speculated that ground outcroppings of asbestos, which are rained on or passed over by ground or surface waters, contribute to the contamination of surface waters by asbestos. Possible areas of naturally occurring asbestos deposits in the U.S. are shown in Figure 5.1. It is impossible to try to quantify this potential contamination at this time. Recycling of wastewaters has already begun at many asbestos manufacturing locations. As wastewater recycling becomes more common or technically feasible, surface water contamination by manufacturers will become less significant. At this time it is not possible to say that asbestos manufacturing wastes contaminate surface waters more than naturally occurring asbestos ground formations.

The most important mode of asbestos release to consider is release of free-fibers to the air. From the manufacturing process, emissions from baghouses or other air cleaning devices represent the greatest potential for airborne release of asbestos fibers in free-form. Table 18.2 estimates that in the neighborhood of 10,000 tons per year are collected in baghouses industry-wide. As previously explained, these collections are either wasted to landfills or waste piles or recycled back to the manufacturing operations. Siebert et al. (1976) has monitored the efficiency of baghouses, with regards to atmospheric emissions, as nearly 99.99%. This would indicate that only 0.01% of baghouse collection would be exhausted to the atmosphere. On the basis of 10,000 tons of collection, about one ton of free-fiber asbestos emissions are released from all asbestos manufacturing plants nationwide using the Siebert efficiency factor. This assumes that all plants use baghouses, which is not necessarily true. Although most plants do use baghouses, a few plants in the past have used air scrubbers and may not have converted to baghouse filters. Section 6.6 estimated that perhaps between 0.1 and 0.2 tons of free-fibers are emitted to the air each year from air scrubbers in the friction material plants. The accuracy of this figure is not certain. Also, the accuracy of applying the Siebert baghouse efficiency of 99.99% to all baghouses industrywide is not certain. In Section 7.3.1, a baghouse emission factor of 1.34 lbs of asbestos fiber emitted per year per 100 CFM rating was developed. For the various reasons given in Section 7.3.1, this factor is probably higher than is the actual case. However, it still appears valid to use such a factor because it was developed from monitoring data; Siebert _et al_. (1976) monitored the typical outlet concentration of a baghouse to be on the order of 10^8-10^9 fibers/m^3 (for fibers > 0.06 μm) and 10^5-10^7 fibers/m^3 (for fibers $\geq$ 1.5 μm).

According to the 1972 Census of Manufacturers (Bureau of the Census), there are about 140 asbestos manufacturing establishments in the U.S. Assuming the ventilation exhaust capacity of these 140 plants averages 50,000 CFM, then the total exhaust industrywide would be 7×10^6 CFM. The emission factor of 1.34 lbs per 100 CFM rating would indicate that roughly 47 tons of asbestos fibers are annually emitted by baghouses. This is a "worst possible" estimate. It should be noted that both estimates of baghouse emissions, one ton and 47 tons, are developed from monitoring data of baghouses which are operating with best practical efficiency. Faulty baghouse equipment or operation can potentially cause significant emissions. Without continual monitoring data from each individual asbestos plant, it is impossible to be more precise on the amount of asbestos emitted by air cleaning devices collectively.

The 99.99% efficiency factor implies that atmospheric emissions from baghouses are proportionally related to the quantity of asbestos fiber collected. This would indicate that the baghouses which collect the most material would release the most emissions. On this basis, friction material manufacturers would be responsible for nearly two-thirds of all baghouse emissions of asbestos. Siebert et al. (1976) monitoring data also indicates that the amount of baghouse emissions is related to the volume of exhaust air. This would indicate that the higher the CFM utilization on a baghouse, the higher would be the mass of fibers emitted. Because of the cleaning requirements from dust generations, it is judged that friction material plants require the greatest CFM volume from baghouses. In terms of air contamination from air cleaning devices, friction material plants are apparently responsible for the largest quantities of asbestos fibers being emitted to the atmosphere from any industry segment.

18.2 Asbestos Emissions from Product Use

Monitoring data are available which indicate that asbestos fibers are released from the normal use of asbestos-containing friction materials (Jacko and DuCharme, 1973; Alste et al., 1976; Rohl et al., 1976, 1977) and from the normal use of A-C pipe under certain conditions (Kuschner et al., 1974; Hallenbeck et al., 1977; Buelow et al., 1977; Craun et al., 1977). There is also monitoring data available to indicate that fibers are released from use of asbestos filters (Nicholson et al., 1973; Biles and Emerson, 1968; Wylie, 1974; Wehman and Plantholt, 1974). Common installation procedures of asbestos patching compounds have been found to release asbestos fibers (Rohl et al., 1975). However, with the exception of the above examples and perhaps a very few others, asbestos release from normal product use of the estimated 3,000 asbestos products has not been monitored.

At this time, the only use of asbestos products which appears to release potentially significant weight units of free-fibers to the general environment is friction material applications. It should be noted that the evidence is inconclusive as to whether asbestos emissions from brake linings have any biological significance. The use of A-C pipe and filters apparently does not release sizeable weight amounts of fibers; however, the concentrations which are released from these uses have caused concerns about adverse health effects because they are released in areas where humans are exposed.

From Section 6.4.2, asbestos emissions from friction materials in vehicles have been estimated to range from 79 tons (using Jacko and DuCharme, 1973, figures) (of which about 2.5 tons become airborne) to 1710 tons (of which about 55 tons become airborne). The latter estimate is made from the Rohl *et al*. (1976) average of 4.5% median asbestos content in wear debris. It may be noteworthy that this amount of asbestos estimated to be emitted to the air from friction material use is higher than the amount of asbestos estimated to be emitted from all industry manufacturing baghouse releases.

18.3 Asbestos Emissions from Product Disposal

As has been explained in the various product sections throughout this report, a certain fraction of current production is destined for product replacements. Additionally, worn-out or damaged products containing asbestos are removed from their use and disposed of, primarily to municipal dumps and landfills. It can be estimated that upwards of several hundred thousand tons of asbestos, contained in the many products, are annually disposed to municipal dumps and landfills.

For the most part, the asbestos fibers in these disposals are bound in some sort of matrix system, whether it be cement, plastic, or asphalt. As indicated earlier, unless these wastes are crushed or incinerated, it is difficult to visualize any significant release of free-fiber asbestos. Demolition operations, especially to friable asbestos products, can release free fibers (EPA, 1974). The amount of asbestos released from demolition operations cannot be satisfactorily quantified on a tonnage basis because enough data is not available.

Carlin (1977) has estimated that of the asbestos products disposed to municipal dumps or landfills, approximately 9% is destined for incineration; the remainder is covered by landfill. Carlin (1977) has additionally estimated that incinceration of asbestos products annually emits about 220 short tons of free-fiber asbestos from all municipal incinerators. The accuracy of this estimate is not certain; Carlin used many assumptions to arrive at his estimate. Carlin (1977) concluded that asbestos air pollution from municipal incinerators amounts to hardly 5% of the total emissions from all mining, milling, fabrication, and disposal operations; and, in addition, that incinerators could be significant, but far from predominant, in causing asbestos air pollution in the United States. However, according to the findings of our current report, Carlin's estimate of 220 tons of emissions would make incineration one of the worst emission sources of free-fiber asbestos to air.

The ability of asbestos to survive municipal incineration has been questioned by several asbestos industry spokesmen. The temperature of a properly operating municipal incinerator should range from 1400-1800°F (Ross, 1970). At about 900°F, chrysotile asbestos decomposes into a different mineral form (Lynch, 1968) such as olivine. Therefore, most of the asbestos fiber should be destroyed by decomposition. However, amphibole asbestos fibers could potentially survive incineration with minor alterations and still be in a biologically active form. Field check is warranted to determine if, and how much, asbestos is environmentally released by incineration.

Asbestos products which are contained in landfills may be subject to leaching by groundwaters. It would seem unlikely, however, that asbestos fibers could penetrate any distance through soil unless there were a significant number of cracks and fissures. A study to determine potential asbestos leaching has apparently never been conducted. This type of study may be desireable.

19.0 SOURCES OF ASBESTOS OTHER THAN FROM ITS COMMERCIAL PRODUCTION AND USE

Rock types in which asbestos minerals might be encountered lie at or near the surface of about 30-40% of the continental United States (Stewart et al., 1977; Kuryvial et al., 1974); Figure 5.1 shows these possible areas. These areas also include most of the economically important mineral deposits. Recovery of these minerals, therefore, produces a potential for the release of asbestos fiber to the environment (Stewart et al., 1977). Kuryvial et al. (1974) investigated 58 mining districts throughout the U.S. and found various types of asbestiform minerals in 16 of the districts. Bronstein et al. (1978) identified chrysotile asbestos in wastewater sources from various ore mining and coal mining operations. Chrysotile concentrations found by Bronstein et al. (1978) are presented in Tables 19.1, 19.2, and 19.3.

At least three sources of inadvertent asbestos contamination, from sources other than commercial production and use of asbestos, have been publicized in recent years. These sources involve asbestos contamination of talc, disposal of taconite tailings containing asbestos, and quarrying for road stones which contain asbestos. This section gives a brief description of these sources.

19.1 Talc

Various types of asbestiform minerals are present in commercially mined talc: anthophyllite accompanies talc mined in the Dadeville deposits of Alabama (Wells, 1975); New York talc from St. Lawrence County is intimately associated with tremolite; and some California talcs are laden with tremolite (Mulryan, 1969). It should be noted that only the infrequently occurring fibrous tremolite is considered to be a true asbestos. Wastewater effluents from a talc mine in upstate New York were monitored to have asbestos concentrations ranging from 10^5 to in excess of 10^8 fibers per liter (Stewart et al., 1977).

Table 19.1. Results of Screen Sample Analysis of Total Fiber and Chrysotile Asbestos (Bronstein _et al._, 1978)

Facility	Ore	Wastewater Source	Total Fiber (fibers/liter)	Chrysotile (fibers/liter)
Alcoa	Al	Treated mine water	1.4×10^9	2.0×10^8
Asarco-Galena	Ag	Treated mine water	5.7×10^7	1.1×10^6
Asarco-Galena	Ag	Tailing pond effluent	2.1×10^9	1.8×10^8
Kennecott-SLC	Cu (02B)	Tailing pond effluent	4.3×10^9	6.7×10^8
Kennecott-SLC	Cu (04B)	Treatment plant effluent	1.5×10^7	7.8×10^5
Kennecott-SLC	Cu (06B)	Tailing pond effluent	3.7×10^7	8.2×10^6
Kennecott-SLC	Cu (08B)	Treatment plant effluent	4.9×10^9	7.7×10^7
White pine	Cu	Treatment system effluent	8.2×10^6	5.5×10^5
Anaconda-Butte	Cu	Tailing pond effluent	1.2×10^9	3.0×10^8
Anaconda-Butte	Cu	Treated mine water	7.2×10^7	8.2×10^6
Bunker Hill	Pb/Zn	Treatment system effluent	4.1×10^8	4.1×10^7
Hecla-Star	Pb/Zn	Tailing pond effluent	1.6×10^9	$<3.3 \times 10^5$
St. Joe-Edwards	Pb/Zn	Tailing pond effluent	3.4×10^8	2.4×10^7
Hanna-Butler	Fe	Mine water settling pond	4.2×10^7	3.8×10^6
Republic	Fe	Tailing pond effluent	4.3×10^7	4.1×10^6
UCC-Uravan	U	Effluent from mill settling pond	1.2×10^9	1.5×10^8
Lucky McMining	U	Treated mine water	5.7×10^8	2.7×10^7
Cotter-Schwartzwalder	U	Treated mine water	2.3×10^9	2.0×10^8
Kerr-McGee	U	Treated mine water	4.3×10^8	5.3×10^7
Placer-Amex	Hg	Tailing pond recycle	7.7×10^8	5.7×10^7
McIntyre Development	Ti	Mill water to recycle	1.5×10^8	1.3×10^6
Pine Creek-UCC	W	Treated mine water	3.3×10^7	8.2×10^6
Molycorp-Questa	Mo	Tailing pond effluent	3.3×10^{10}	2.0×10^9

Table 19.2. Results of Screen Sample Analysis of Total Fiber and Chrysotile Asbestos (U.S. Steel - Geneva Mine) (Bronstein *et al.*, 1978)

Facility	Sample (W58-XI-Coal)	Wastewater Source	Total Fiber (fibers/liter)	Chrysotile (fibers/liter)
Geneva Mine (E. Carbon, UT)	01B	Wastewater Storage Tank Overflow	8.8×10^8	8.6×10^7
Geneva Mine (E. Carbon, UT)	02B	Carlson Pumps Discharge (Minewater)	1.3×10^9	1.4×10^8
Coal Preparation Plant (Wellington, UT)	05B	Settling Pond Decant	3.7×10^8	1.6×10^7

* Corresponding Blank - 2.2×10^5 fibers/liter
Detection Limit - 3.3×10^5 fibers/liter

Table 19.3. Results of Screen Sample Analysis of Total Fiber and Chrysotile Asbestos in Coal Mining (Bronstein et al., 1978)

Company/Mine	Versar Code	Total Fiber (fibers/liter)	Chrysotile (fibers/liter)
Duquense Light Co./Warwick #2	NC-20	1.2×10^9	2.7×10^8
North American Coal/Conemaugh #1	NC-21	7.3×10^7	6.6×10^6
Central Ohio Coal Co./Muskingum	NC-22	8.6×10^7	3.7×10^6
Peabody Coal Co./Sunnyhill	T-5	1.4×10^7	3.1×10^6
Eastern Associated Coal Corp./Joanne	NC-14	5.5×10^8	1.2×10^7
Valley Camp Coal Co./Mine #6	PN-11	3.4×10^7	7.8×10^5
Bethlehem Mines Corp./Boone #131	NC-15	1.3×10^8	5.4×10^6
Island Creek Coal/Pocahontas #3	NC-16	4.1×10^{10}	7.5×10^8
Bethlehem Mines/Pike #26	NC-11	3.3×10^7	1.6×10^6
Falcon Coal Co./Haddix Operations	NC-12	3.4×10^9	1.0×10^8
Consolidation Coal/Matthews	NC-17	1.5×10^{10}	1.9×10^5
Amex Coal Co./Ayshire	NC-8	1.9×10^9	1.9×10^5
Island Creek Coal Co./Hamilton #1	NC-10	1.8×10^{10}	1.9×10^5
Peabody Coal Co./Will Scarlet	NC-9	3.1×10^8	3.4×10^6
Southwestern Illinois Coal Co./Captain	NC-7	4.0×10^9	3.9×10^7
Peabody Coal Co./Bee Veer	NC-5	2.2×10^9	2.0×10^7
Texas Utilities/Fairfield	V-6	5.2×10^{10}	8.3×10^8
Decker Coal Co./Decker #1	NC-1	5.1×10^7	1.9×10^5
Western Energy/Colstrip	NC-2	5.2×10^9	1.4×10^8
National Mines Corp./Isabella	NC-19	2.1×10^9	5.7×10^7

The Mount Sinai researchers, including Selikoff, Rohl, Langer, and Nicholson, completed a talc study in late 1975 which identified asbestos in commercial cosmetic preparations of talc in amounts ranging from 2-20% (Anon., 1976e). The FDA, however, said that results of its 1975 survey of 76 commercial cosmetic talc products did not find asbestos.

Mount Sinai discovered that talc used to coat short-grained rice may also contain asbestos (Anon., 1976e). Merliss (1971) states that talc-coated rice in Japan has asbestos present as a contaminant.

U.S. talc mines produce roughly 1.2 million tons of talc each year (Wells, 1975). Because the amount of asbestos which may be present in some talc ores varies from deposit to deposit, it is very difficult to estimate the tonnage quantity of asbestos which may appear as a contaminate. It becomes more difficult, if not impossible, to then attempt to estimate the quantity which may become exposed or emitted to the environment. An extensive amount of monitoring data would be required to make an accurate estimate. This type of monitoring data does not exist at this time.

19.2 Taconite Wastes

Taconite is a hard, low-grade ore, containing only 25% of finely dispersed iron in the form of hematite or magnetite. Years of research resulted in the development of a practical process for the up-grading of magnetic taconite for use by steelmakers. In brief, the process involves pulverization of the taconite ore and a magnetic separation operation to make pellets which contain 65% iron. About three tons of taconite ore are processed to produce one ton of taconite concentrate pellets. The remaining two tons are waste tailings of a siliceous nature (Schmitt *et al.*, 1977).

The Reserve Mining case brought to national attention the contamination of Lake Superior with asbestos particles from taconite tailings. Since 1955 the Reserve Mining Company has been discharging about 67,000 tons of tailings suspended in 2 million tons of water to Lake Superior each day (Anon., 1977e). The tailings in this discharge contain trace amounts of several metals, but mostly they contain billions of amphibole silicate (asbestiform) fibers. The heavier fibers sink by the force of gravity to the bottom of the lake, but the lighter, buoyant fibers travel with the prevailing currents to Duluth, Minnesota and Superior, Wisconsin, to become part of these cities' drinking water (Anon., 1977e). Monitoring of drinking water systems in this region has yielded amphibole fiber counts of 0.02 to 12.4 million fibers/liter via electron microscopy analysis (Fairless, 1977).

19.3 Rock Quarries

At the present time, the Environmental Protection Agency is in the process of studying the crushed stone industry to determine the asbestos content of serpentinite rock at quarrying operations (Anon., 1977d). The controversy over asbestos content of some crushed stones began when Rohl et al. (1976) published results of a study of crushed serpentinite quarried in Montgomery County, Maryland. The stone had been extensively used for paving roads, parking lots, and driveways. Air samples taken in the vicinity of these paved roads showed that some chrysotile concentrations were about 1,000 times greater than those typically found in urban ambient air in the U.S. Monitored concentrations in Montgomery County ranged from extremely low readings to readings as high as 17 million fibers/m^3 and 6400 ng/m^3 (Anon., 1977d). As noted in Section 6.4.2.1 of this report, normal urban concentrations of airborne asbestos are commonly less than 30 ng/m^3.

It is impossible to attempt to quantify asbestos emissions from such sources until a great deal more monitoring data is available.

19.4 Summary

Without quantitative estimates it is difficult to assess the potential environmental contamination by indirect asbestos sources relative to the commercial asbestos industry. The commercial asbestos industry is restricted in certain areas as to the emissions or concentrations of asbestos which may be permitted by the EPA or by OSHA. With a few exceptions, such as Reserve Mining, the sources of asbestos release other than the commercial asbestos industry, are apparently not regulated for asbestos emissions. In this regard, the potential of these sources to emit asbestos into the general environment deserves a great deal more study; the data which is available is extremely sparse.

20.0 SUMMARY ASSESSMENT

This report has focused on the commercial manufacture and use of asbestos products. It has attempted to quantify the amounts of asbestos fiber consumed by each of the major end-use industry segments and has attempted to estimate the quantities of asbestos which may be emitted to the environment from manufacturing and product use. For the most part, quantity emission estimates were predicted from engineering assumptions and the relatively small amounts of monitoring data which were applicable. The accuracy of the emission estimates made in this report should be regarded as "ballpark" estimates at best. More precise emission estimates for manufacturing and product uses require additional monitoring data of a rather extensive nature. Although the basic manufacturing operations within a particular industry segment are common to nearly all of the individual factories, slight variations, especially in terms of disposal techniques, can cause one factory to emit a much greater amount of asbestos than another. A plant by plant monitoring program would be required to predict a precise total amount of asbestos fiber released to the environment from manufacturing. For the purposes of this report it was necessary to assume average disposal methods and pollution abatement methods within a particular industry segment. The estimates which have resulted from these assumptions are at least helpful in describing the magnitude of possible emissions.

The greatest amount of airborne fibers directly released by asbestos product manufacturers is judged to come from baghouse emissions. Although the baghouses used in the asbestos industry have been determined to have an exceptional efficiency, a very large number of small fibers are emitted each year by baghouse exhausts. An attempt to quantify baghouse emissions has resulted in estimates ranging from one to forty-seven tons per year. The highest value is considered as a severest possible emission. The exact fate of airborne asbestos fibers is not known with certainty. Whether the fibers remain airborne, settle to the ground, or are washed from the air by precipitation may depend upon particle size and other factors; however, there is nothing available in the literature to quantitatively predict the result. From the available data and estimates, it appears that plants manufacturing friction materials, particularly brake linings, are responsible for a significant portion of all baghouse emissions from product manufacture. Certain disposal techniques of free-fiber manufacturing wastes may also contribute significant amounts of free-fibers into ambient air. However, available monitoring data is not sufficient to quantify these releases.

As far as asbestos emissions from use of asbestos products are concerned, friction materials appear to be by far the most serious polluter of any of the asbestos products. Estimates of annual airborne fiber emissions from brake linings range from 2.5 to 55 tons, and this represents only about 3% of the total brake emissions of asbestos. However, the evidence is inconclusive as to whether the emission of asbestos from brake linings has any biological significance.

Relatively small amounts of asbestos fibers are emitted by the use of some asbestos-cement pipes, depending upon the quality of water being transported. Water which is particularly acidic is susceptible to causing erosion from walls of A-C pipe, thereby releasing fibers in concentrations as high as a million fibers per liter of water. Because A-C pipes are extensively used to transport drinking water in the United States, release of small quantities of fibers may cause considerable concern. The potential threat to human health from the amounts of fibers which may be released by A-C pipes is beyond the scope of this report. However, it should be noted that the proper use of A-C pipe, as outlined by the American Water Works Association, releases only extremely small amounts of fibers or none at all.

Two consumer uses of asbestos, which have been determined to expose humans to dangerous levels of airborne fibers, have been banned by the Consumer Products Safety Commission. These uses are patching compounds and artificial fireplace embers.

For the most part, however, most asbestos containing products have not been monitored for fiber release during use. In a very high percentage of applications, the asbestos fibers are bound in a matrix system, such as asphalt, cement, or plastic, which makes fiber emission extremely difficult under normal use.

As this report has noted, asbestos is a unique and very useful fiber due to its properties and characteristics. Asbestos is widely used not only because it is economical, but also because it is the best available material for nearly all of its applications. Products made with asbestos serve a very useful purpose in the American industrial and consumer market. It is unfortunate that the most widely used consumer product containing asbestos, brake linings in automobiles, is also one of the major identifiable sources of asbestos fiber emission into ambient air. In present-day drum brake lining and clutch facing use, asbestos presence is almost essential. No other fiber or material performs the job requirements nearly as well as asbestos. In disc brake pad area, steel fiber reinforced semimetallic friction materials have enjoyed increased usage; in model year 1978 the projected usage is for $\sim$17% of the U.S. production of passenger cars and $\sim$13% of light trucks (Jacko, 1978a).

Semimetallic disc pads are specified for certain after-market replacements and semimetallic brake blocks are also installed on heavy trucks as aftermarket replacements to the original equipment materials which are asbestos-based. Alternate materials have been tested and are considered inferior. In practical terms, it will probably be a number of years before asbestos can be totally eliminated from automobile brake linings, disc pads, and clutches. Replacement of asbestos will be accompanied by cost penalties due to increased material and processing costs.

Demolition of buildings containing asbestos has been shown to emit asbestos fibers. Quantification of these emissions is not possible because necessary monitoring data are not available. Therefore, no comparison on the magnitudes of releases in relation to asbestos manufacturing or product use can be made.

Likewise, the amounts of asbestos emitted by product disposals is difficult to estimate. The most serious consideration of the wasting of asbestos products may be potential airborne emissions resulting from incineration. One estimate of fiber emission from incineration is 220 tons per year. The accuracy of this figure is not certain. However, this estimate would make incineration the largest single airborne polluter of asbestos fibers. The generation of monitoring data in this regard seems highly desirable.

The mining and milling of asbestos have only been briefly touched upon in this report. The various U.S. mines and mills have been identified in Section 5.0 and the respective productions have been listed. However, no estimates have been made as to the quantities of asbestos fiber which may be released to the environment from mining and milling operations. Therefore, it is impossible to attempt to compare emissions from mining and milling versus manufacturing or product use. Although mining and milling are generally considered to contribute more fibers into the environment than manufacturing per unit of processed asbestos, it should be remembered that over 85% of the asbestos consumed in this country is imported.

Asbestos fibers are also emitted by sources which are not directly connected to the asbestos industry. Natural ground formations of asbestiform minerals can apparently release fibers into rivers and ground waters; however, the quantities or concentrations of asbestos which can be attributed to these natural sources has not been determined at this time. Asbestiform minerals are also present in some talc, taconite, and rock quarries which are commercially mined in the United States. Available monitoring data indicate that asbestos emissions from these sources may potentially create dangerous exposure levels to humans. However, because quantitative emission estimates are not available for these sources, it is not possible to compare asbestos product manufacturing and use with them.

To summarize, asbestos fibers are emitted into the general environment from a variety of sources. These sources include asbestos mining and milling, asbestos product manufacturing operations, use of some asbestos-containing products, disposal operations to various asbestos products, and varied mining and natural sources. Sufficient data are not available to predict which of the above sources are primarily responsible for the asbestos fibers which have been monitored in general ambient air and potable water samples. Air monitoring in localized areas has indicated that specific sources contribute significant levels of asbestos into ambient air in that particular area. These specific sources include crushed serpentinite stone containing serpentine asbestos used to pave roads and driveways, demolition of buildings containing asbestos construction materials, and automotive brake linings adjacent to toll plazas where cars brake to a stop. An extensive program of specialized monitoring is required to determine, with any certainty, the degree of responsibility which may rest with a potential emission source in terms of the total urban air environment.

This report has, however, estimated a general magnitude of emission from asbestos product manufacturing and from automotive brake lining use. It has also identified municipal incineration as a potential source of significant asbestos fiber emission to ambient air. It is probably reasonable to judge that urban air levels of asbestos are caused by a combination of brake emissions, municipal incineration, building demolition, and product manufacturing. It is further judged that elimination of asbestos from brake linings could significantly reduce urban air levels of asbestos.

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